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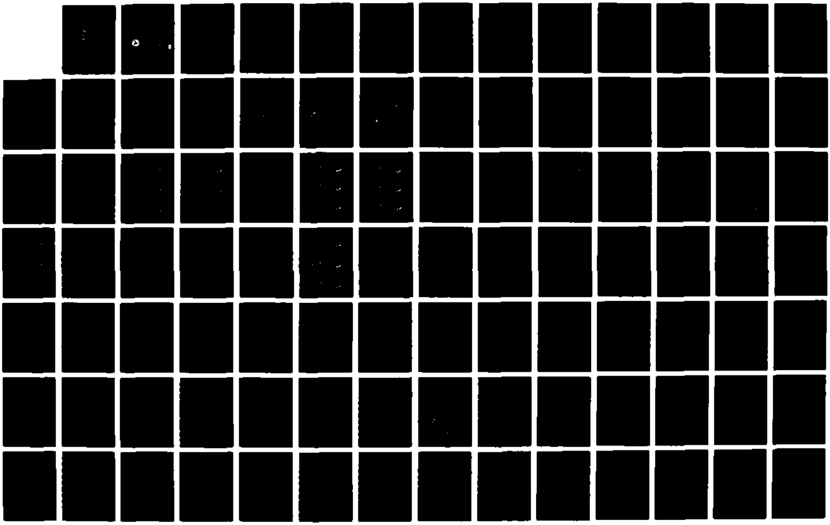

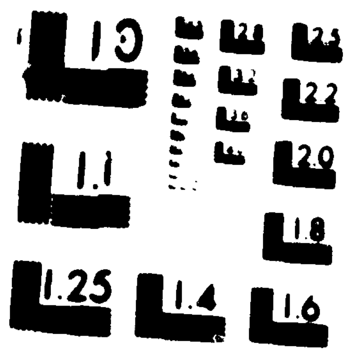
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ARCTIC DRIFTING BUOY DATA 1979 - 1985

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AVERY POINT, GROTON, CONNECTICUT 06340-6096

FINAL REPORT
APRIL 1987

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16. Abstract

As part of an investigation into the fate of potential Arctic oil spills, the U.S. Coast Guard Research and Development and Canadian Marine Drilling, Ltd. (CANMAR) released satellite-tracked dirfting buoys at two sites in the southern Beaufort Sea during six years (1979-1983, 1985). The sites were near Canadian offshore drilling locations off the Tuktoyaktuk Peninsula, Northwest Territories and near Prudhoe Bay, Alaska.

An analysis of the trajectories of these buoys indicated that the majority of buoy drift was in an alongshore (east/west) direction. When buoys did move in a north/south direction, their speeds were generally lower and the length of excursions shorter.

A comparison of the drift of these buoys to the calculated geostrophic wind (east/west component only) revealed that, over a long term, the buoys drifted, on average, with the mean wind. Buoys had average drift speeds which varied from 1% to 5.5% of the mean wind. When cumulative drift was compared to the cumulative wind, high correlations were noted for those buoys with spar type hulls. This indicates that the cumulative large-scale geostrophic wind plays an important role in the cumulative movement of the upper 1-2 meter of the water column.

A comparison of the trajectories of buoys which were released in close spacial and time proximity was conducted. In general, their drifts were variable enough to indicate that the total forcing function on separate buoys was different.

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METRIC CONVERSION FACTORS

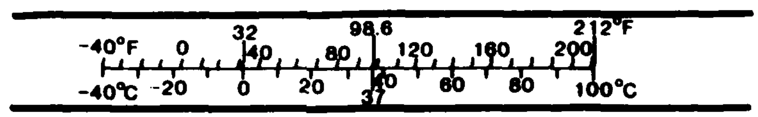
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENTS

In that this experiment was begun in 1979 and included the deployment of buoys in two locations during six years, the collection of data from these buoys, and the development of computer software to process this data, there are numerous individuals whose contributions have been important to the development of this report. The deployment of the buoys off of the Tuktoyaktuk Peninsula, Northwest Territories was accomplished with the assistance of Jim Steen of the Canadian Marine Drilling Ltd. and his crew. Without his logistical and financial support, the bulk of this experiment would not have been possible. Individuals from the Coast Guard R&D Center who were important to this experiment included Ivan Lissauer, who has been the project manager for the Arctic Pollution Response project since 1978. He was instrumental in the development and implementation of this experiment from its inception. His insight into the physical aspects of the Beaufort Sea's surface currents were highly valuable in the development of this report. Another is Dr. Don Murphy who was the manager of this experiment from 1979 to 1982. He led the development of data collection and analysis techniques and provided valuable insight to the author while this report was being developed. R. Quincy Robe, who developed the techniques used to filter and interpolate the raw position data and provided assistance in buoy deployment techniques, was also a valuable resource.

Others who assisted in buoy deployments and/or data collection included John Meyers, Pete Tebeau, Jim Willcox, Art Allen, Tim Noble, Sandy Shedlack, and Denise Baird. Computer software development assistance was provided by Don Cundy and Mike Couturier.

Without the assistance and input of these individuals over the course of seven years, this experiment would not have been the success that it is.

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1.0 INTRODUCTION

The exploration for oil and gas under the Beaufort Sea has given rise to the possibility that a serious oil spill incident could occur. Even with the recent drop in world oil prices, exploration and future planning for development of these resources has continued. If a spill does occur, the ability to predict the movement of the spilled oil on water or under ice will be of utmost importance.

Since 1979, the Coast Guard Research and Development Center (R&DC) has been working with Canadian Marine Drilling, Ltd. (CANMAR), a subsidiary of Dome Petroleum, in an effort to determine the long range patterns of the Beaufort Sea's surface currents. The primary technique which has been used to determine these currents has been the deployment of satellite tracked drifting buoys. The area of study has extended from Amundsen Gulf northeast of the Tuktoyaktuk Peninsula, Northwest Territories (NWT) to the Chukchi Sea west of Point Barrow, Alaska (Figure 1-1).

The purpose of this report is to present the results of six years of buoy drift data (1979 - 1983 and 1985) in a final report with a like analysis of the trajectories of these buoys. These data have been previously presented by Murphy, et al. (1981), Murphy, et al. (1983), Robe, et al. (1984), and St. Martin and Lissauer (1986).

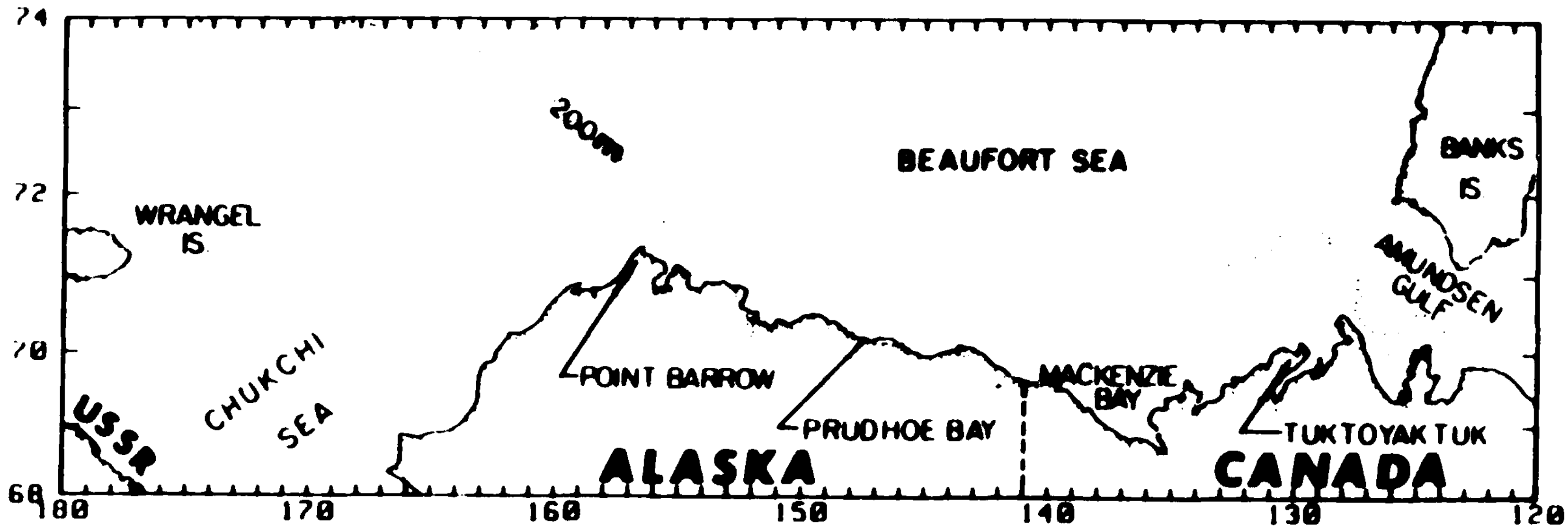


FIGURE 1-1. AREA OF STUDY

2.0 BACKGROUND

The long term surface currents of the Beaufort Sea are generally considered to flow westward with the Arctic Gyre. However, the effect of local winds or significant episodes of long term winds may alter the westward flow for specific areas or periods of time. When planning for oil exploration under the Beaufort Sea was being considered (near Prudhoe Bay, Alaska and the Tuktoyaktuk Peninsula, NWT), the R&DC and CANMAR decided to work cooperatively in order to determine the extent of variability in these currents. If the surface currents of the southern Beaufort Sea turned out to be consistently westward (as was expected prior to the start of this experiment) the problem of predicting the long term movement of spilled oil would be much easier to solve. However, if this was not the case, a predictive technique which included the input of local meteorological data would need to be developed to estimate the long term movement of spilled oil. Therefore, the deployment of satellite tracked drifting buoys was undertaken to test the assumption that the long term drift in the southern Beaufort Sea would be generally to the west.

3.0 DATA COLLECTION AND PROCESSING

3.1 Tracking System and Buoy Descriptions

The buoys used during this experiment were tracked with two different systems. The Random Access Measurement System (RAMS) on board the polar orbiting NIMBUS-6 satellite (see Kirwan, et al. for a summary of RAMS) was used in 1979. During the other five years that buoys were released, tracking was performed with the ARGOS system on board the TIROS/NOAA series of polar orbiting satellites. Bessis (1981) provides a description of this system. The position accuracies of the RAMS and ARGOS systems are advertised as ± 5 km and ± 300 meters respectively. For both systems, positions are determined by a doppler shift in the carrier frequency of buoy transmissions during a satellite pass.

Three different designs of buoy platforms were used during this study. Two of these were designed and manufactured at Polar Research Laboratories (PRL), Santa Barbara, California while the third was designed and constructed at Scripps Institute of Oceanography (SIO). The first type (Figure 3-1) was designed by CANMAR and was deployed by them off the Tuktoyaktuk Peninsula, NWT. It is 1.12 m in diameter with a 0.2 m drag skirt. It floats nearly awash with only a 0.38 m antenna protruding above the hull. It will be referred to as the CANMAR buoy. The second type was deployed off Prudhoe Bay, Alaska by the CG R&DC as well as off the Tuktoyaktuk Peninsula, NWT by CANMAR. These are spar type buoys, approximately 3 meters long. This type (Figure 3-2) floated with approximately 2.5 m of the buoy in the water and the remaining 0.5 m above the water surface. It will be referred to as the PRL buoy. The third type was used during 1979 and was deployed off the Tuktoyaktuk Peninsula, NWT. It consisted of a fiberglass cylindrical hull approximately 3 meters long (Figure 3-3). It will be referred to as the SIO buoy.

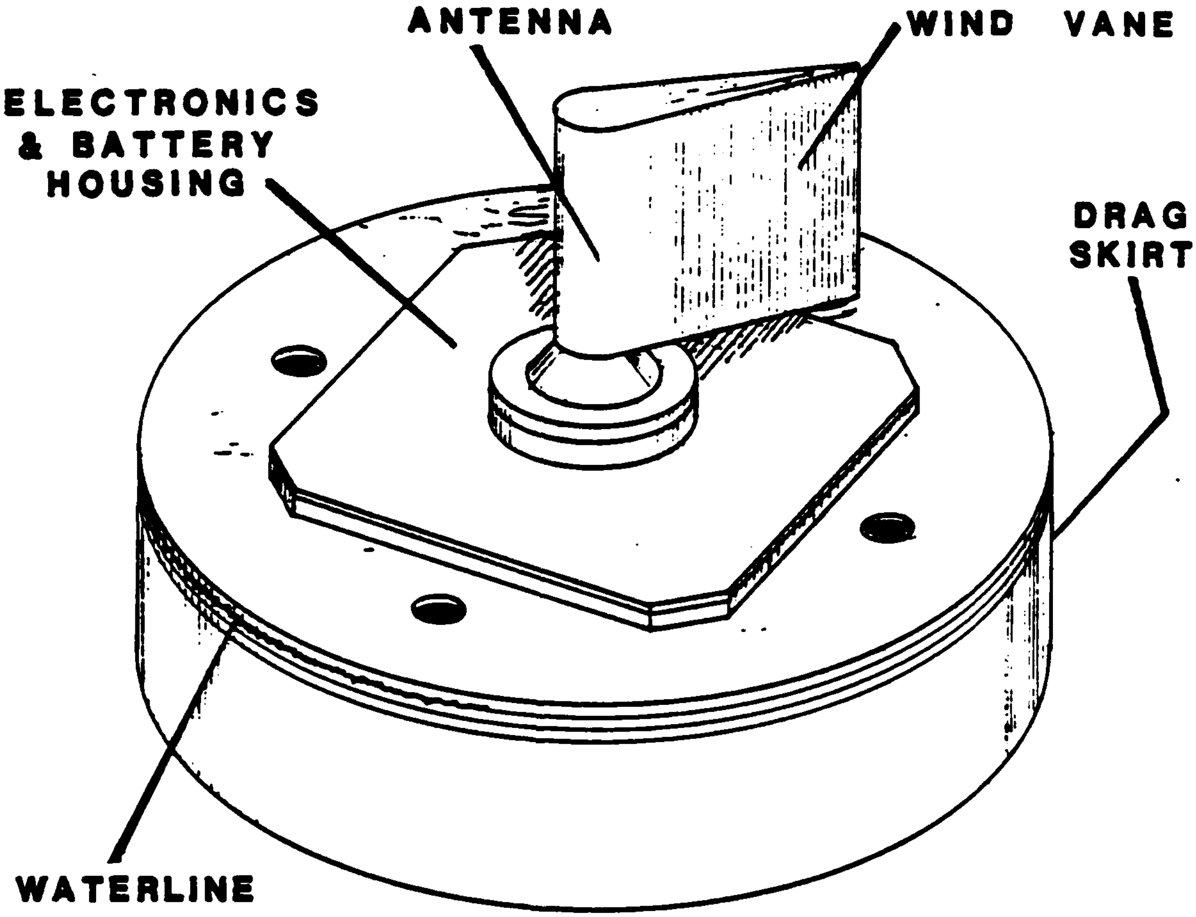


FIGURE 3-1. CAMMAR HULL DESIGN
(Murphy, et al., 1983)

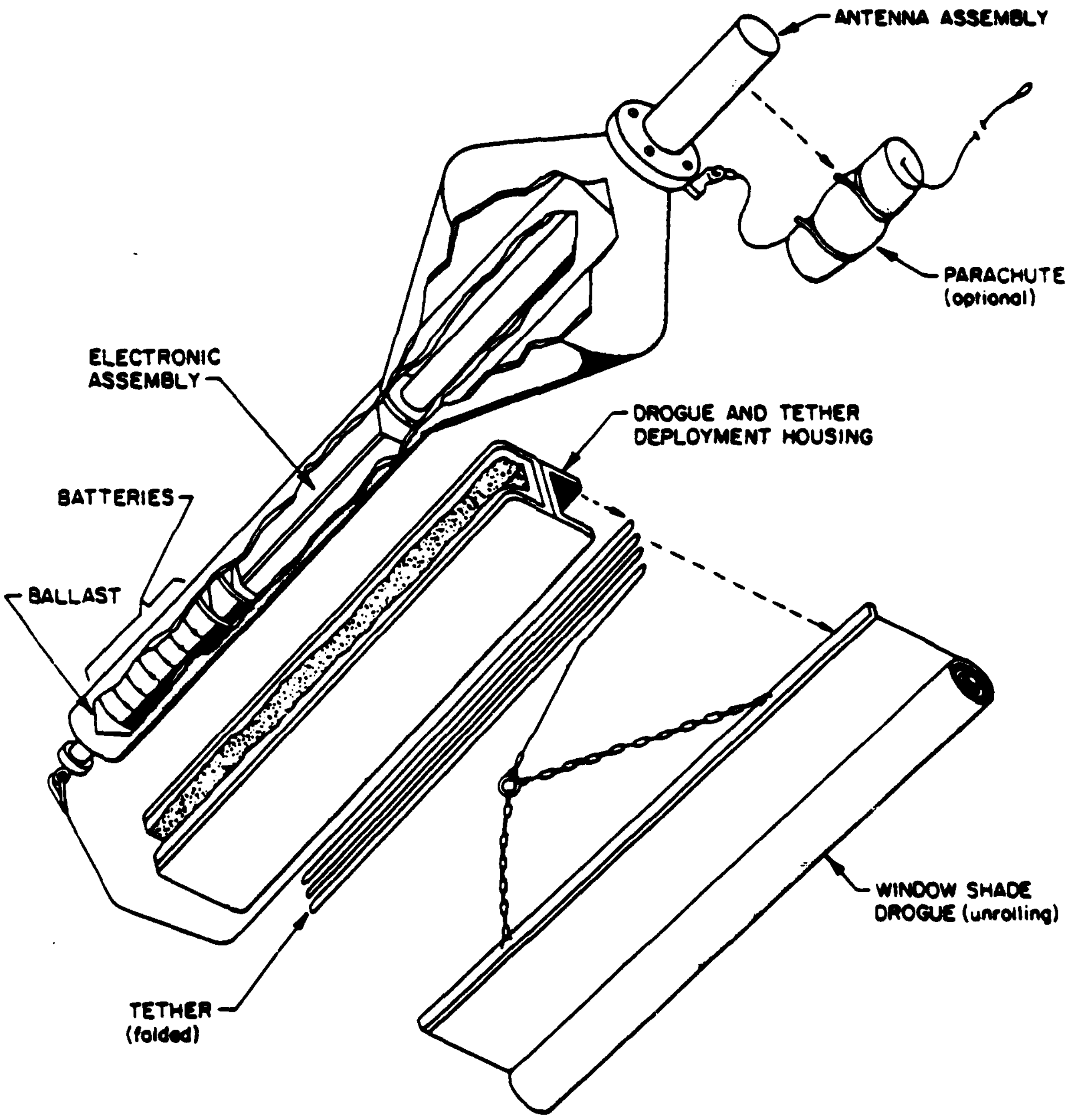
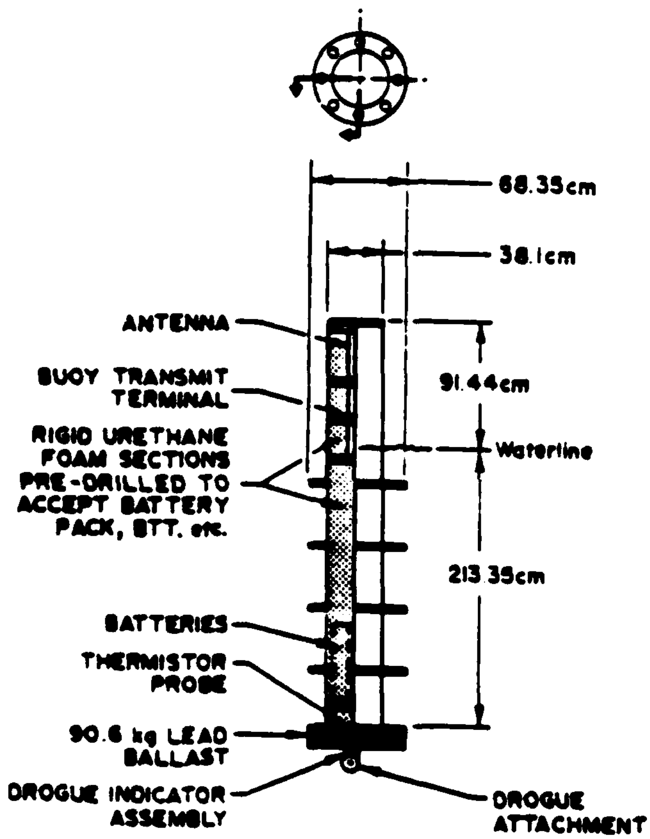


FIGURE 3-2. POLAR RESEARCH LABORATORY (PRL) HULL DESIGN (Murphy, et al., 1983)



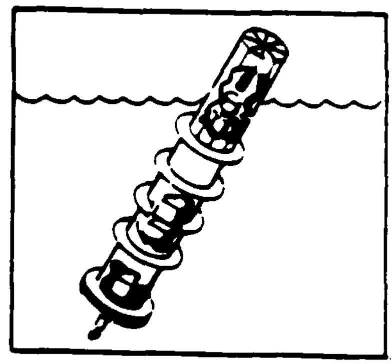


FIGURE 3-3. SCRIPPS INSTITUTE OF OCEANOGRAPHY (SIO) HULL DESIGN (Murphy, et al., 1983)

During 1980, 2x11 meter nylon window shade drogues were tethered by a 30 meter nylon line to the PRL buoys which were deployed. A drogue sensor was built into the buoy connection point and provided a drogue on/off indication along with each position. Due to difficulties in determining if this sensor was providing a correct signal and the shallowness of the water (approximately 50 m), the early positions of four of the 1980 buoys is somewhat suspect. A complete discussion of this problem can be found in Murphy, et al. (1983).

Since the purpose of this study was to determine the variability of surface currents over a long time frame, as a method of examining the possible drift of oil spilled on the Beaufort Sea, the ability of the buoy types used in mimicking the movement of spilled oil is of the utmost importance. Generally, these buoys follow the upper 1 - 2 meters of the water column. An additional factor which may cause their drift to be slightly different than oil drift is the effect of the force of the wind on the exposed portion of a buoy. However, since the ratio of the area of incidence of the submerged portion of the hull to the exposed portion for each buoy type is somewhat high (approximately 2:1 for a PRL buoy, 4:1 for a CANMAR buoy, and 2.3:1 for an SIO buoy), any error of this type encountered is considered insignificant for the purposes of this study. Kirwan, et al. (1978) attempted to correct buoy trajectories for the effect of local winds. They found unrealistically high corrections and concluded that uncorrected trajectories were a better representation of the surface currents.

3.2 Position Data Processing

For the 1979 buoys, position information was sporadic due to the nature of the satellite transits over the area (sometimes

four or five times in one day and at other times a gap of ten days). On average, 1.4 positions per day were recorded. Consequently, data processing was less sophisticated and consisted of a simple two point linear interpolation to produce two processed positions per day (at 1200 and 2400). No filtering was attempted.

For the other years in which data was collected, a more sophisticated satellite system with a larger number of satellites provided for an average of 10 positions per day. This data was processed according to the method recommended by Robe and Maier (1979). Equally spaced position records with a three hour time interval were computed using a four point linear interpolation scheme. These position records were then low pass filtered with a cut-off of 1.16×10^{-5} Hz (one cycle per day). This filtering removes random system errors and most of the tidal effects.

For all data, buoy drift speeds and directions were computed from the interpolated or filtered (if available) position files by a simple two point backward differencing scheme. Histograms of speed and direction were developed.

When applicable, horizontal separation distances between buoys were calculated for each position record in which trajectory data overlapped. Distances were calculated by converting the latitude/longitude positions to spherical coordinates and assuming that the the earth is a perfect sphere. The distance between these coordinate pairs were calculated directly. The use of this information will be presented in Section 5.3.

3.3 Wind Data

Wind data for 1979 - 1983 were calculated from twelve hour isobaric charts obtained from the National Center for Atmospheric Research (NCAR). The calculations of these data were performed by determining a pressure differential at two locations of the Beaufort Sea (eastern and western sides). These differentials were used to calculate the average U (east/west) component of the wind for each 12 hour interval. A further discussion of the method used to calculate the geostrophic wind is presented in Section 5.2.

4.0 YEARLY BUOY TRAJECTORIES

This section describes the trajectories of the buoys which were deployed in 1979 through 1983 and in 1985. A total of 35 trajectories (5 SIO, 15 CANMAR, and 15 PRL buoys) from successfully deployed buoys are presented in chronological order of release date. For each trajectory figure, the location of deployment is indicated by an arrow.

4.1 1979 Buoys

Seven freely drifting SIO buoys with NIMBUS electronics were deployed into ice-free waters at CANMAR drilling sites northwest of the Tuktoyaktuk Peninsula in August 1979 (see table 4-1 for summary). Three buoys were released on August 9th and four on August 30th. Of the seven buoys, one stopped transmitting immediately and another ran aground on Richards Island within a few hours. The remaining five buoys (Figures 4-1a to 4-1e) traversed the southern Beaufort Sea in an east-to-west direction.

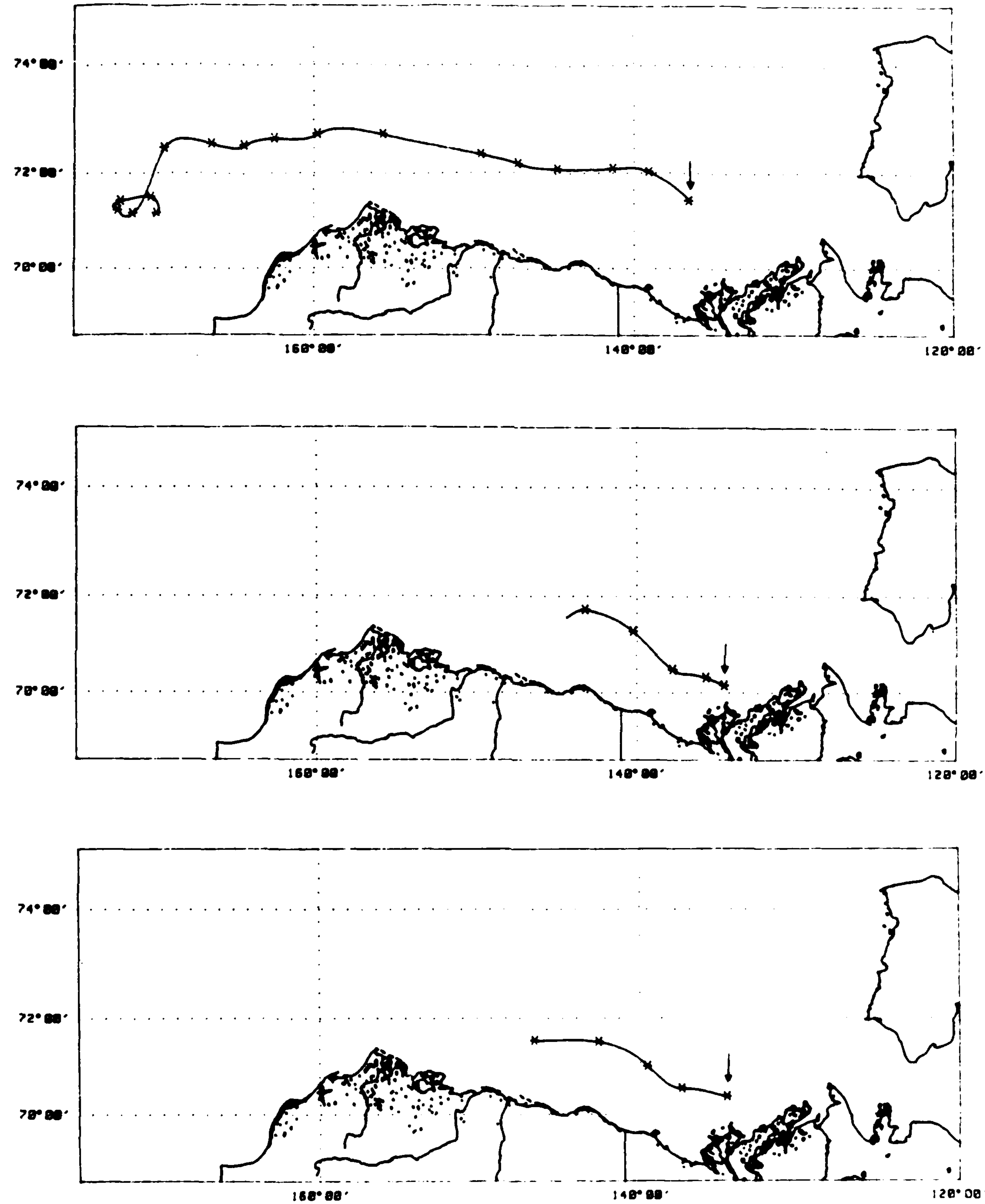
The three buoys which were released on August 9 moved rapidly to the northwest throughout August and continued to move westward along the Beaufort Sea coast approximately 200 Km offshore in relatively ice-free waters (Figures 4-1a to 4-1c). Approximately 2 months after deployment, they turned somewhat towards the southwest after passing Pt. Barrow, Alaska and entering the Chukchi Sea. By February 11, 1980 all three buoys had ceased transmitting.

The two remaining buoys were released on August 30 and these also initially moved rapidly to the northwest then to the west along the Alaskan coast (Figures 4-1d and 4-1e). These buoys moved somewhat inshore of the other buoys. During October, 1979, while in the vicinity of Pt. Barrow, they ceased transmitting.

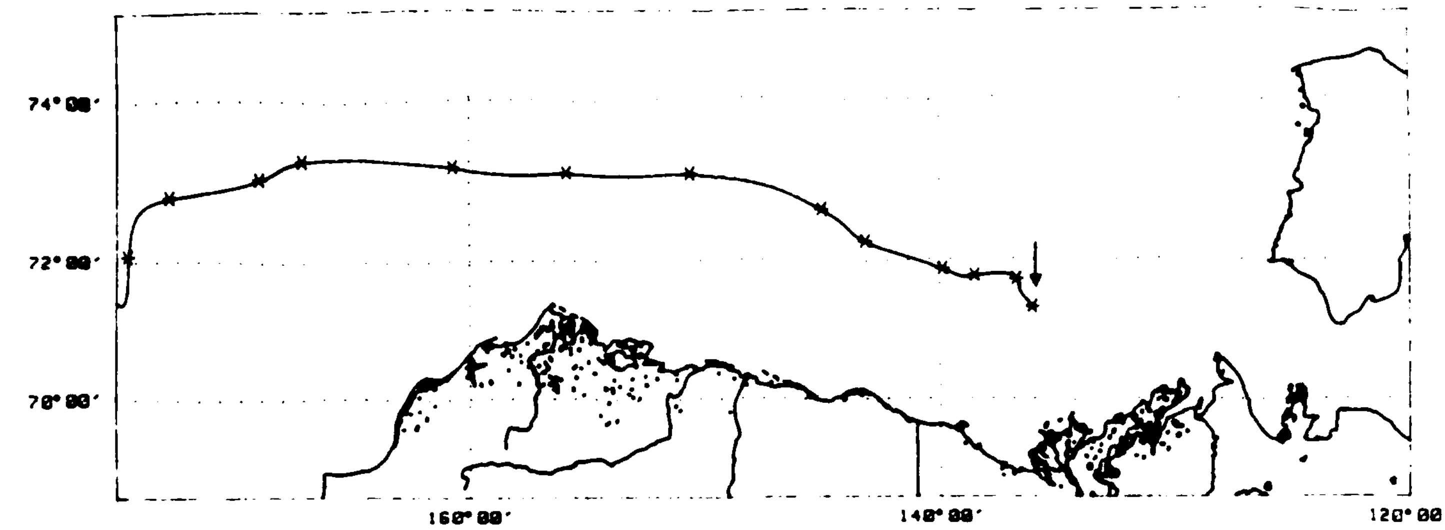
TABLE 4-1.

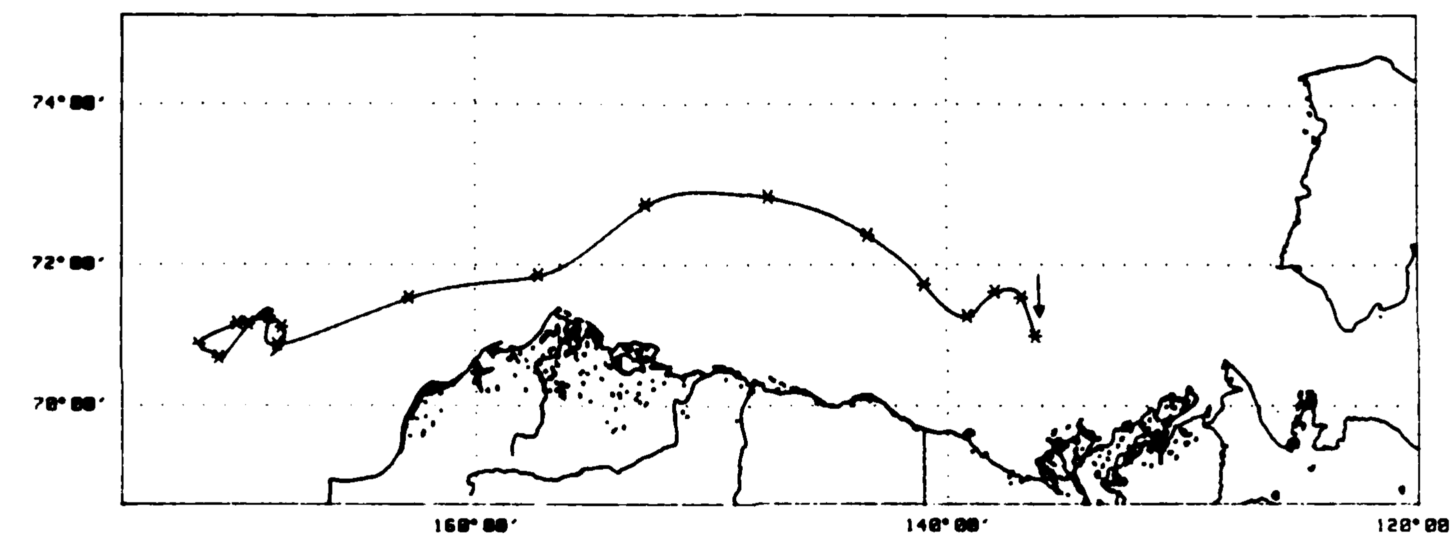
1979 BUOY DATA SUMMARY

ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	RELEASE DATE	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
226	SIO	70-16	133-22	9 Aug 1979	31 Dec 1979
235	SIO	70-03	133-22	30 Aug 1979	FAILED
257	SIO	70-09	133-24	30 Aug 1979	FAILED
261	SIO	70-20	133-27	30 Aug 1979	22 Oct 1979
404	SIO	70-31	133-28	30 Aug 1979	19 Oct 1979
432	SIO	70-27	133-24	9 Aug 1979	30 Nov 1979
443	SIO	70-05	133-20	9 Aug 1979	11 Feb 1980



FIGURES 4-1a through 4-1c. **TRAJECTORIES OF BUOYS 226, 261, AND 404, (1979), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.**





FIGURES 4-1d and 4-1e. TRAJECTORIES OF BUOYS 432 AND 443, (1979), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.

4.2 1980 Buoys

In August and September, 1980, eight buoys were released to the northwest of the Tuktoyaktuk Peninsula, NWT. Table 4-2 provides a summary for these buoys.

Of the eight buoys, one (2590) stopped transmitting immediately after being deployed and two others (2584 and 2588) only worked for a few days. Trajectories for the other five buoys are shown as Figures 4-2a to 4-2e. All five buoys initially traveled eastward until late September. One buoy (2589) entered into Franklin Bay where it ran aground in mid-September. Another (2583) moved a short distance to the east for five weeks when it stopped transmitting. In late September, the trajectories for the other three buoys (2581, 2582, 2587) reversed to an east-to-west movement. They transmitted long enough to be tracked along the southern Alaskan Beaufort Sea coast for a period of time until their signals were lost.

4.3 1981 Buoys

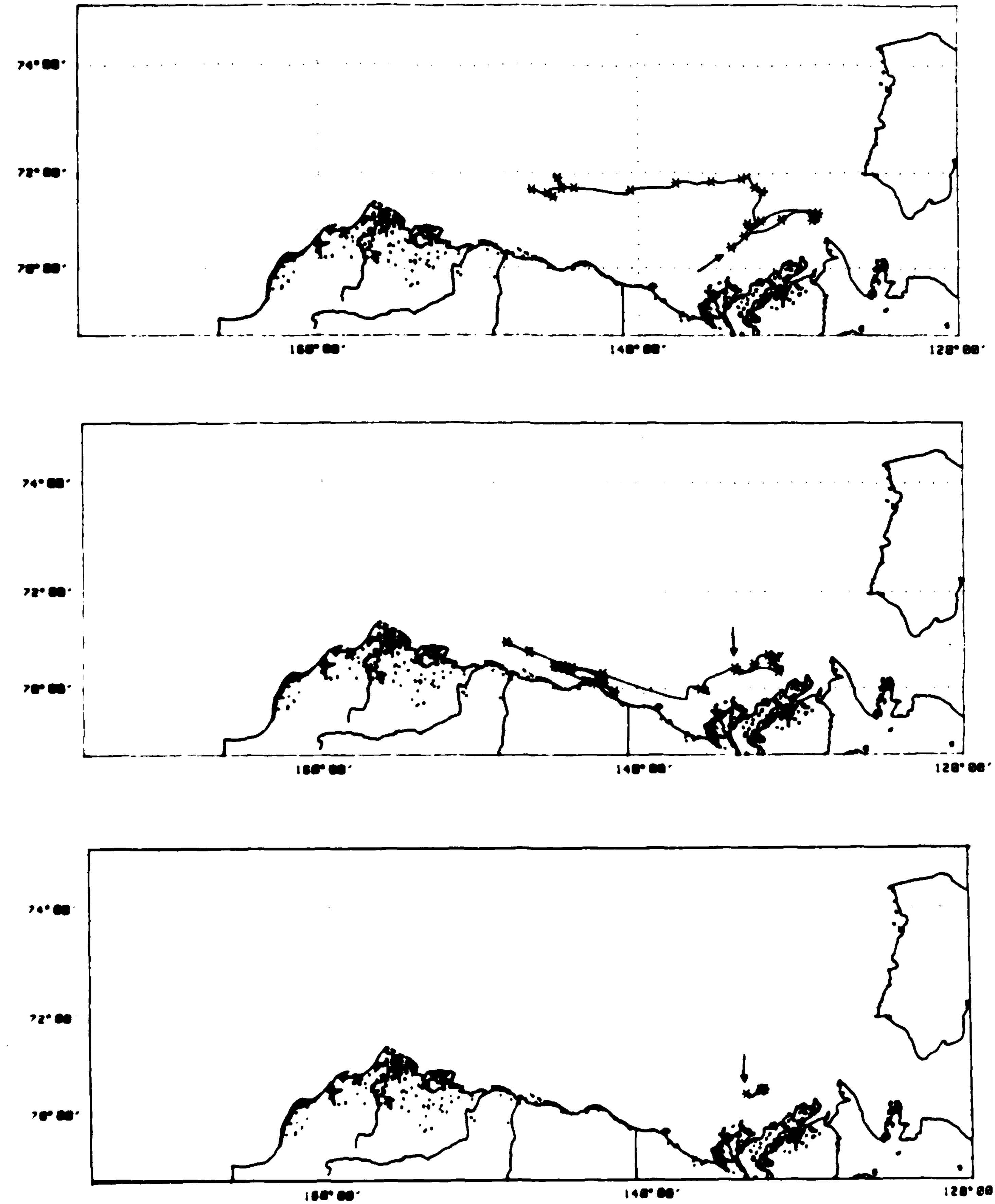
In the summer of 1981, eight buoys were again released off the Tuktoyaktuk Peninsula, NWT. Table 4-3 provides a summary of these buoys deployments. One (2602) failed immediately upon release and another (2603) was retrieved without authorization by a passing tug. Of the remaining six buoys, five traversed from west-to-east and grounded along the Canadian coastline around early September. The remaining buoy (2604) moved in various directions for 6 weeks before traversing east-to-west until it stopped transmitting in early November while off the Alaska coast. Trajectory plots for these buoys are shown as Figures 4-3a to 4-3f.

TABLE 4-2.

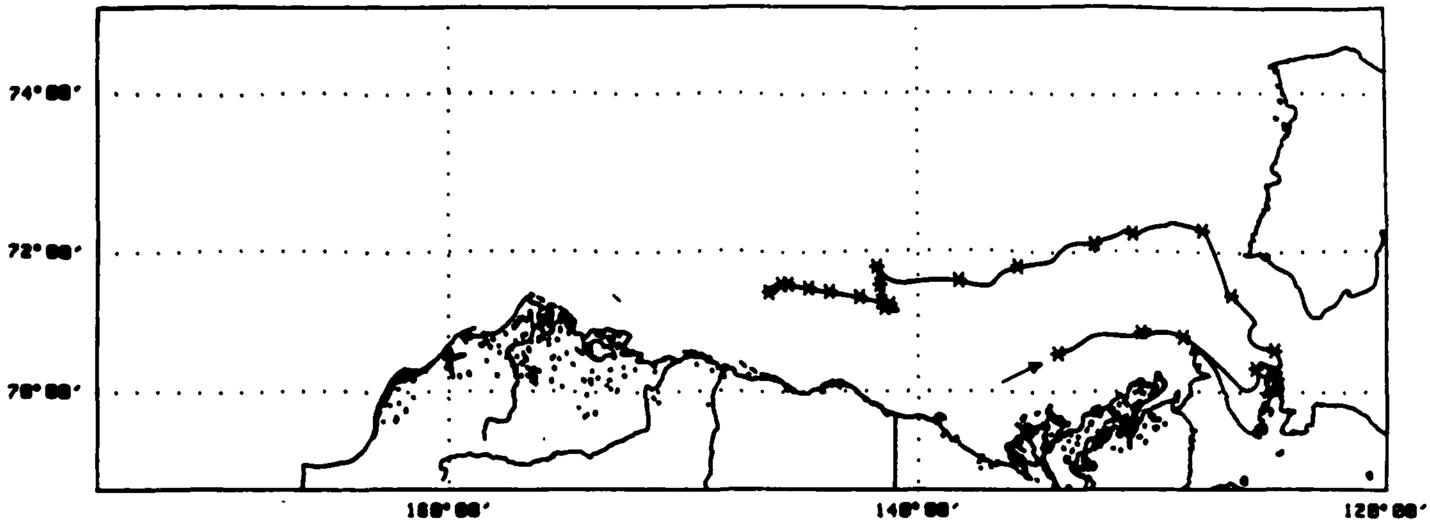
1980 BUOY DATA SUMMARY

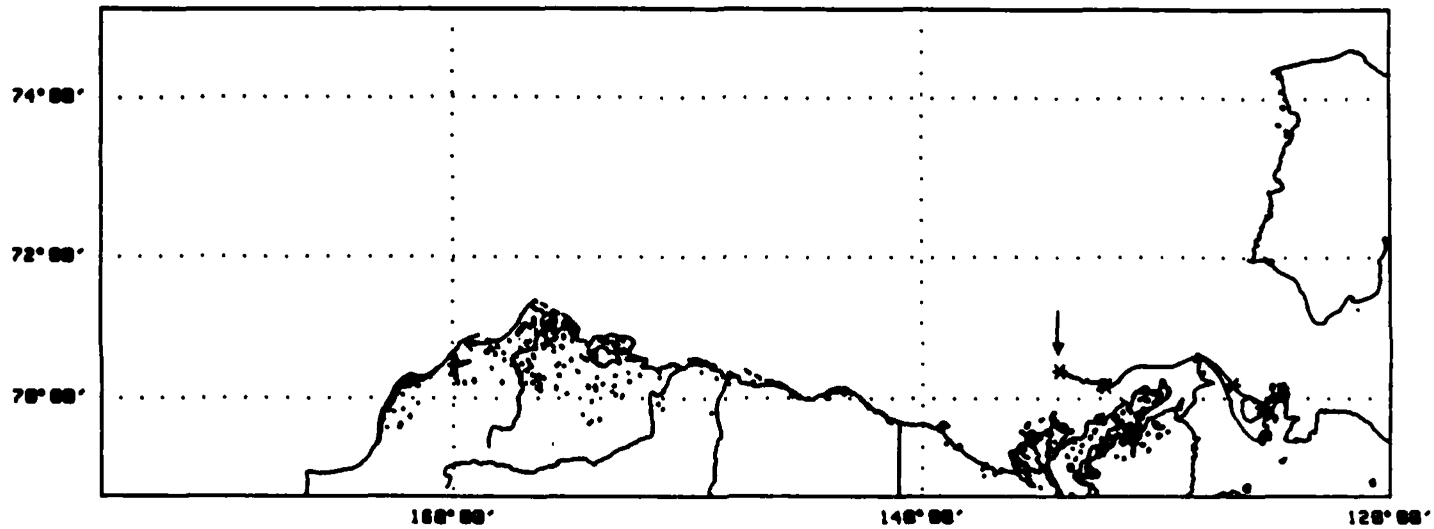
ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	RELEASE DATE	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
2581	PRL	70-22	134-08	17 AUG 1980	7 JAN 1981
2582	PRL	70-22	134-08	21 AUG 1980	11 MAY 1981
2583	PRL	70-22	134-08	21 AUG 1980	29 SEP 1980
2584	PRL	70-22	134-08	13 AUG 1980	13 AUG 1980
2587	CANMAR	70-22	134-08	21 AUG 1980	21 FEB 1981
2588	CANMAR	70-22	134-08	29 AUG 1980	1 SEP 1980
2589	CANMAR	70-22	134-08	25 AUG 1980	17 SEP 1980
2590	CANMAR	70-22	134-08	2 SEP 1980	FAILED

Notes: PRL buoys were drogued when released
Buoys 2582, 2583, and 2587 were released together



FIGURES 4-2a through 4-2c. **TRAJECTORIES OF BUOYS 2581, 2582, AND 2583 (1980), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.**





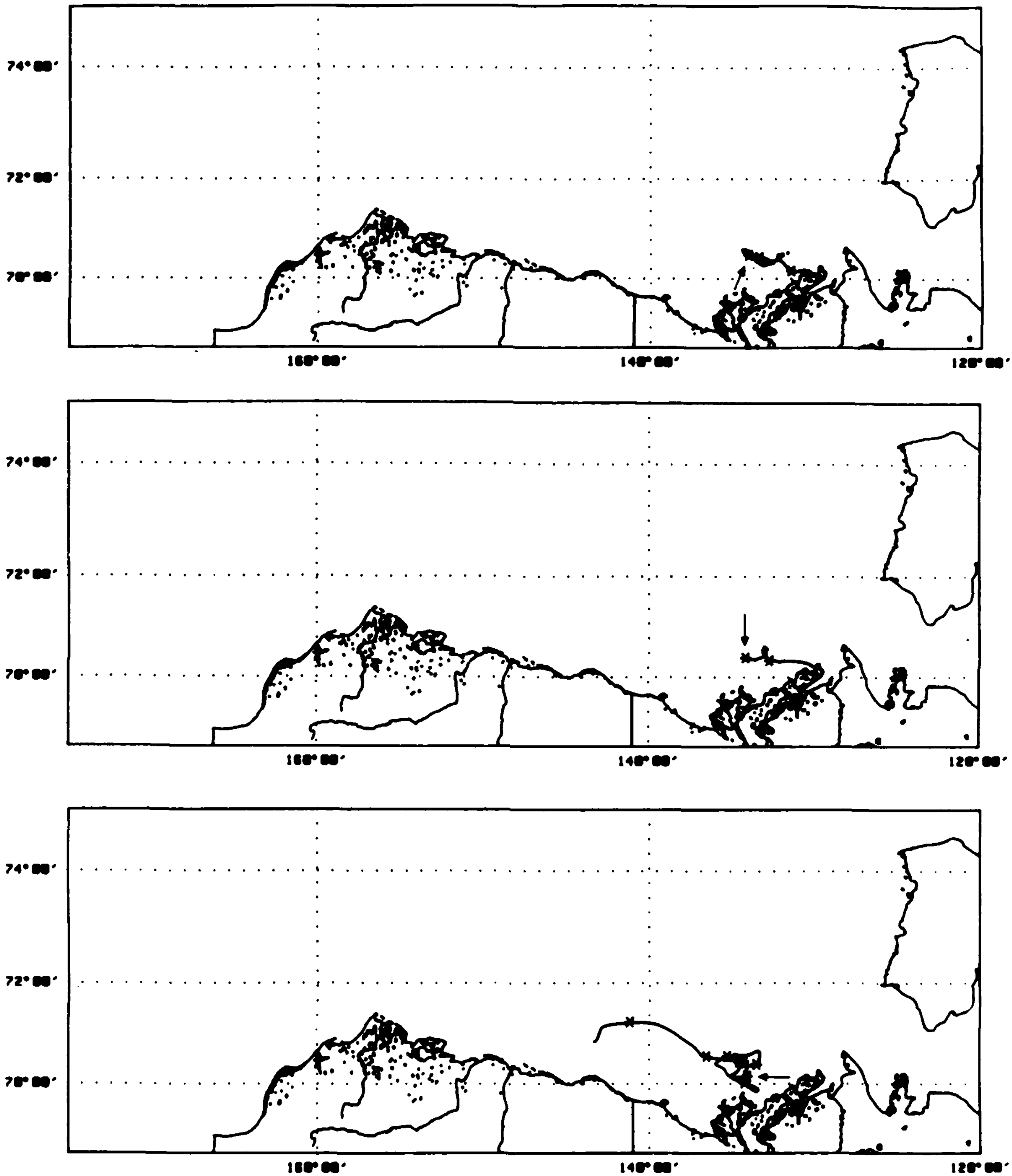
FIGURES 4-2d and 4-2e. TRAJECTORIES OF BUOYS 2587 AND 2589 (1980), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.

TABLE 4-3

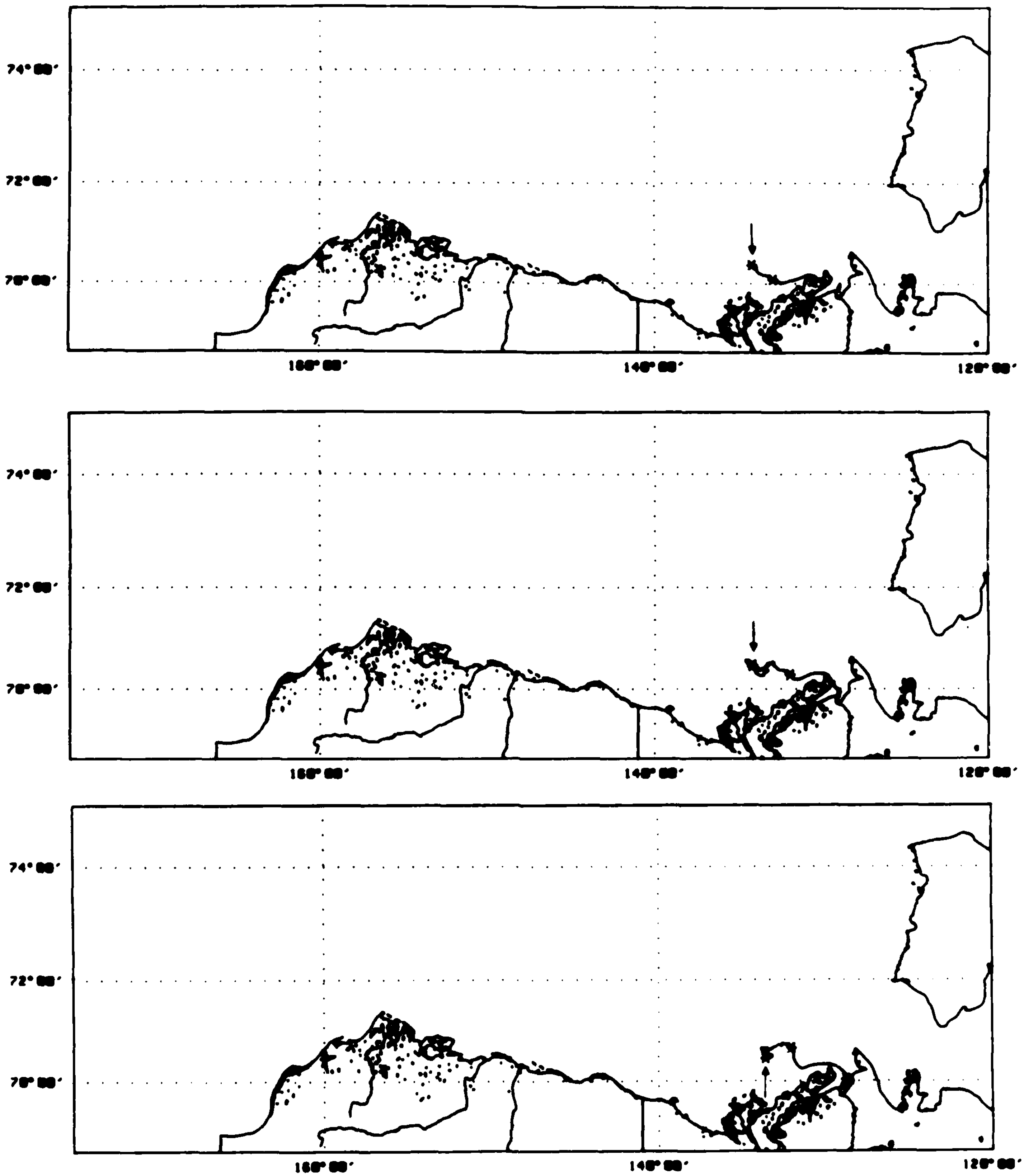
1981 BUOY DATA SUMMARY

ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	RELEASE DATE	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
2600	PRL	70-22	134-08	15 AUG 1981	30 AUG 1981
2601	PRL	70-22	134-08	22 AUG 1981	2 SEP 1981
2602	PRL	70-22	134-08	15 AUG 1981	FAILED
2603	PRL	70-22	134-08	5 SEP 1981	RETRIEVED[1]
2604	CANMAR	70-22	134-08	4 SEP 1981	4 NOV 1981
2605	CANMAR	70-22	134-08	22 AUG 1981	1 SEP 1981
2607	CANMAR	70-22	134-08	15 AUG 1981	3 SEP 1981
2608	CANMAR	70-22	134-08	18 AUG 1981	4 SEP 1981

Note: (1) Retrieval was unauthorized



FIGURES 4-3a through 4-3c. TRAJECTORIES OF BUOYS 2600, 2601 AND 2604 (1981), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.



FIGURES 4-3d through 4-3f. TRAJECTORIES OF BUOYS 2605, 2607 AND 2608, RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.

4.4 1982 Buoys

In September, 1982 four buoys were released to the northwest of the Tuktoyaktuk Peninsula, Canada. A summary of these deployments is presented in Table 4-4. All four buoys operated successfully. Initially, they traveled from east-to-west until early to mid October. One buoy (4507) ran aground on the Canadian coast and another (4508) ceased transmitting while north of the Alaska coast. Buoy 4505 moved west-to-east from mid October until late December when it reversed direction and then stopped transmitting in mid January. The remaining buoy (4506) began to move towards the southeast in mid October. After another month its movement became more east-to-west along the Alaska Coast. It stopped transmitting in late January while off Alaska. Trajectories for these buoys are shown as Figures 4-4a to 4-4d.

4.5 1983 Buoys

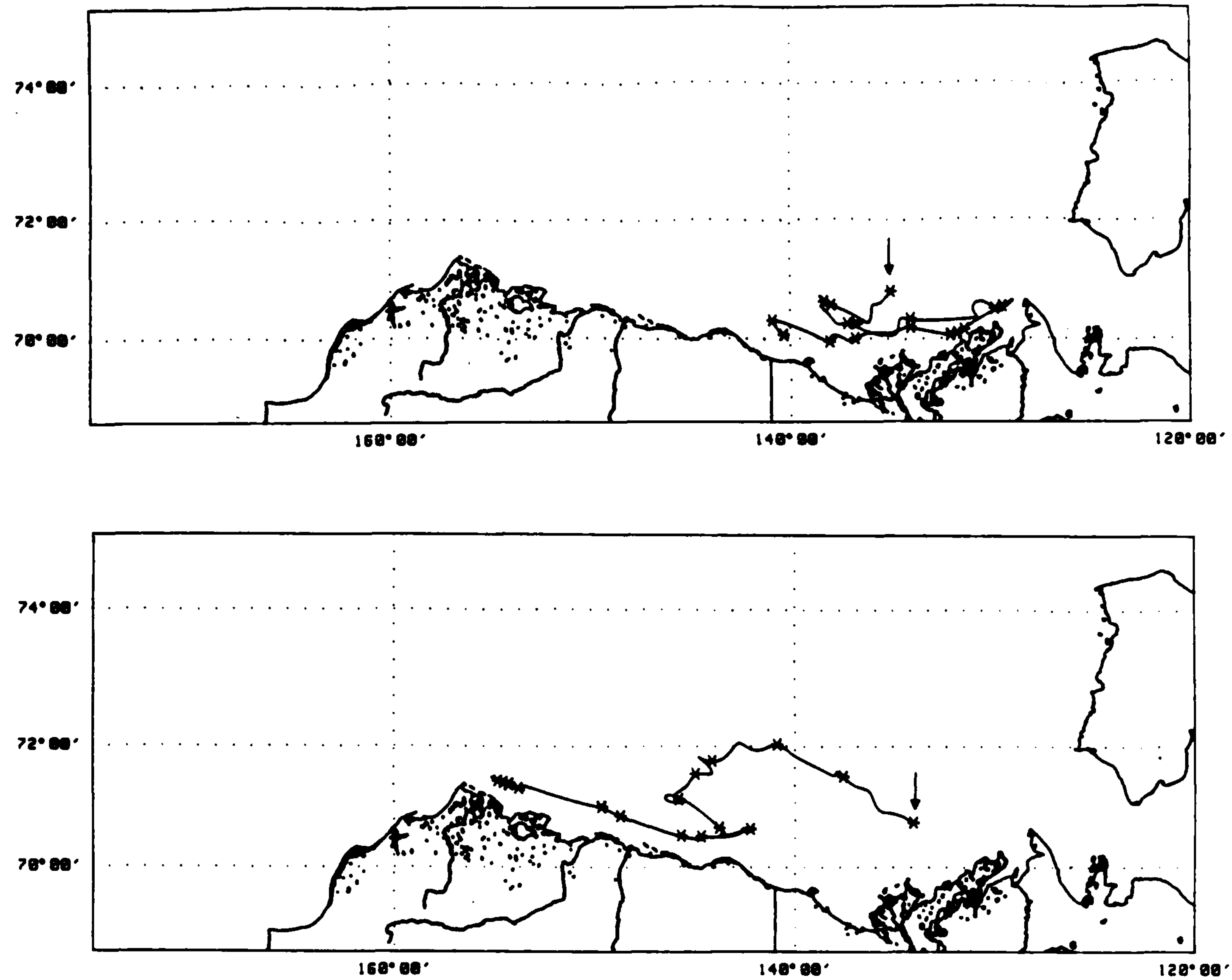
In August, 1983 ten buoys were released in the southern Beaufort Sea. Six of these were released near Prudhoe Bay, Alaska and four were released to the northwest of the Tuktoyaktuk Peninsula, NWT. One of the Prudhoe Bay releases (4516) failed immediately. Table 4-5 provides a summary of these deployments.

In general, these buoys overall movement was from west-to-east until mid October (if still transmitting). At that point, only buoys 4519 and 4523 were either still transmitting or not aground. Buoy 4519 traveled to the northwest until mid December then moved very slowly in various directions until it ceased transmitting. Buoy 4523 moved east-to-west until late December then also moved in various directions at a slow speed until transmissions ceased. Figures 4-5a to 4-5i show the trajectories of these buoys.

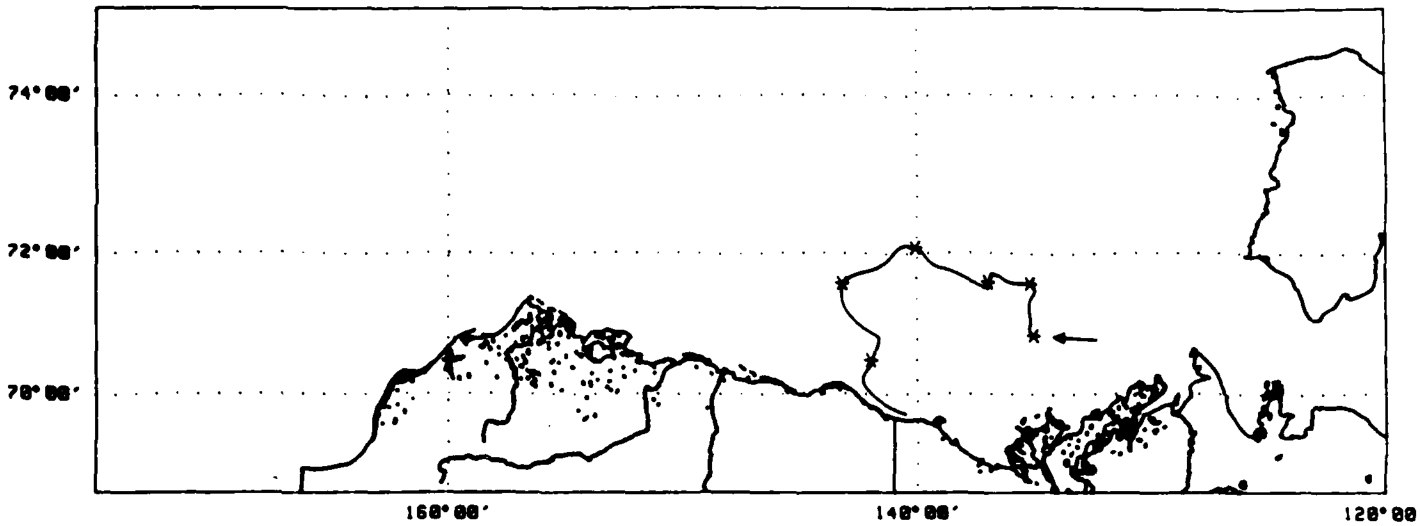
TABLE 4-4

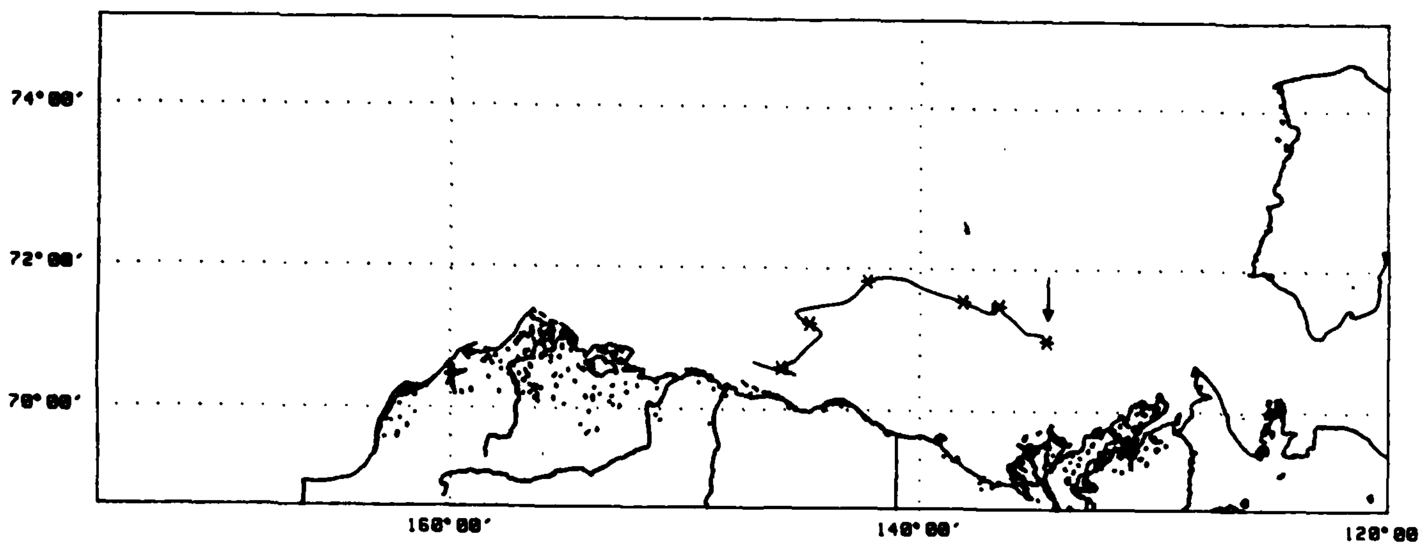
1982 BUOY DATA SUMMARY

ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	RELEASE DATE	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
4505	CANMAR	70-45	134-10	12 SEP 1982	10 JAN 1983
4506	CANMAR	70-44	134-00	7 SEP 1982	25 JAN 1983
4507	CANMAR	70-42	134-10	1 SEP 1982	15 OCT 1982
4508	CANMAR	70-44	134-00	4 SEP 1982	19 OCT 1982



FIGURES 4-4a and 4-4b. TRAJECTORIES OF BUOYS 4505 AND 4506 (1982), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.





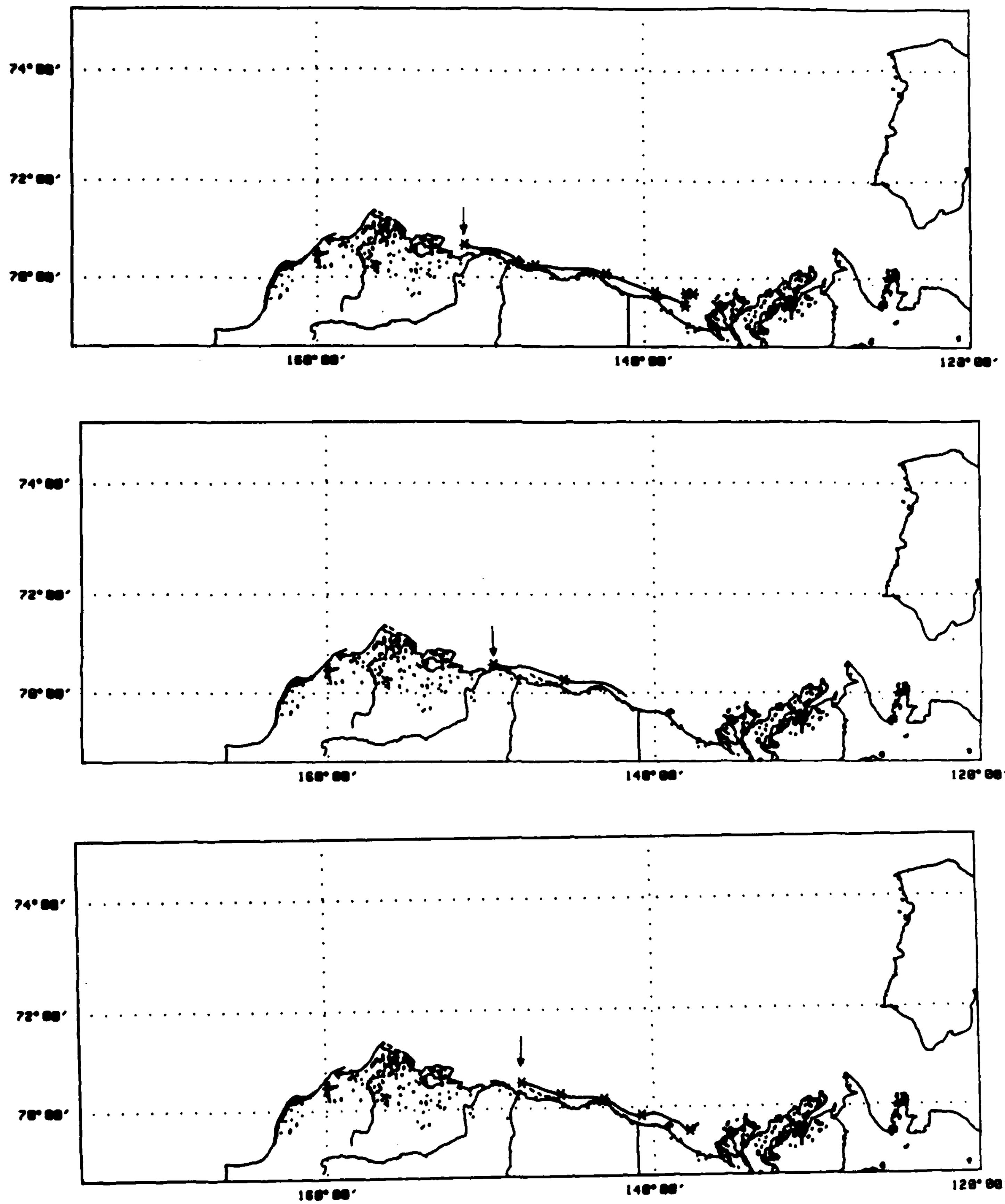
FIGURES 4-4c and 4-4d. TRAJECTORIES OF BUOYS 4507 AND 4508 (1982), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.

TABLE 4-5

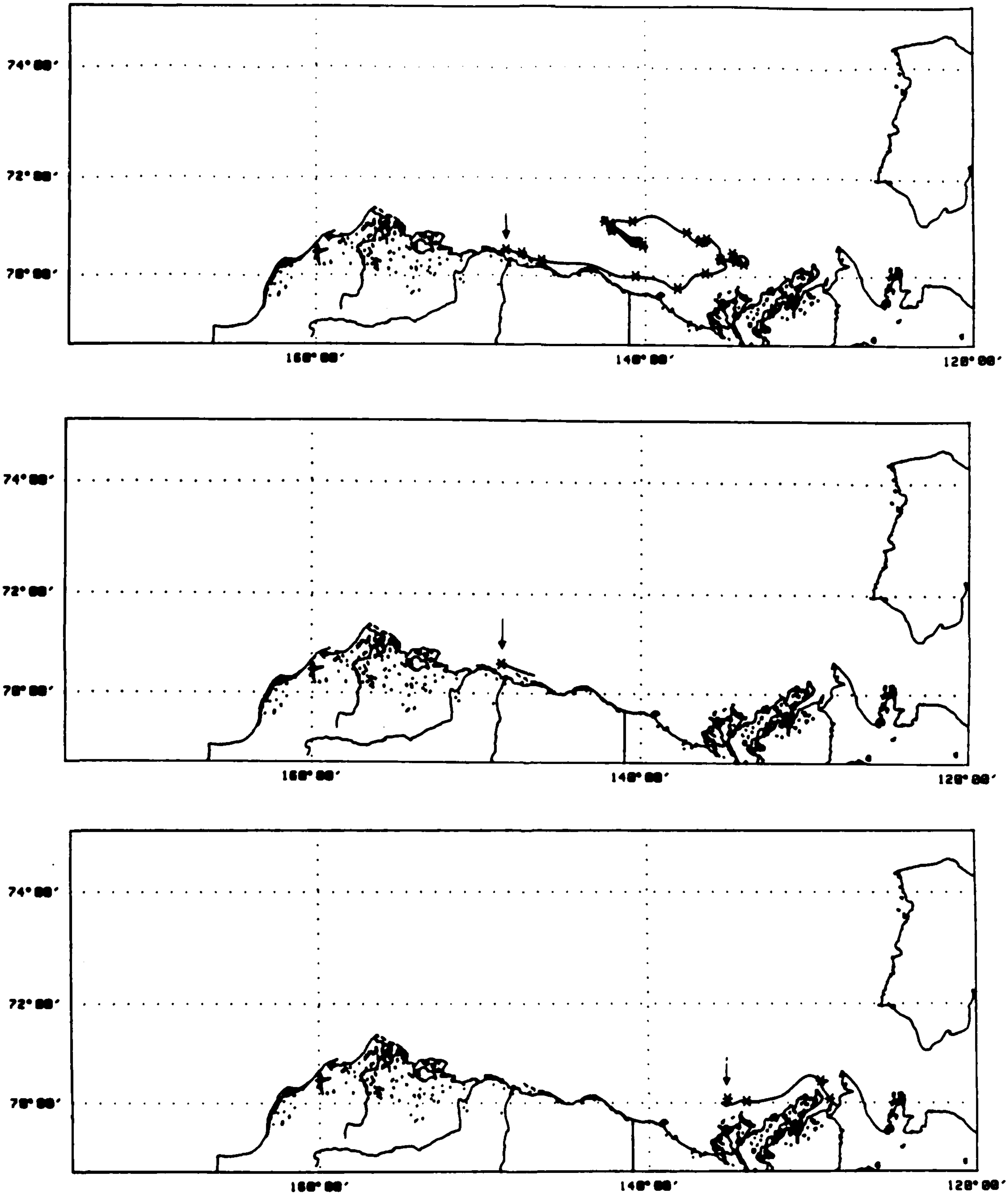
1983 BUOY DATA SUMMARY

ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	RELEASE DATE	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
4515	PRL	70-35	148-46	11 AUG 1983	12 OCT 1983
4516	PRL	70-35	148-43	11 AUG 1983	FAILED
4517	PRL	70-35	148-39	11 AUG 1983	4 SEP 1983
4518	PRL	70-32	148-39	16 AUG 1983	24 SEP 1983
4519	PRL	70-38	149-01	16 AUG 1983	23 FEB 1984
4520	PRL	70-34	148-53	16 AUG 1983	27 AUG 1983
4521	CANMAR	70-15	135-18	25 AUG 1983	25 SEP 1983
4522	CANMAR	70-19	135-38	23 AUG 1983	30 SEP 1983
4523	CANMAR	70-26	136-25	17 AUG 1983	2 FEB 1984
4524	CANMAR	70-19	135-26	19 AUG 1983	11 OCT 1983

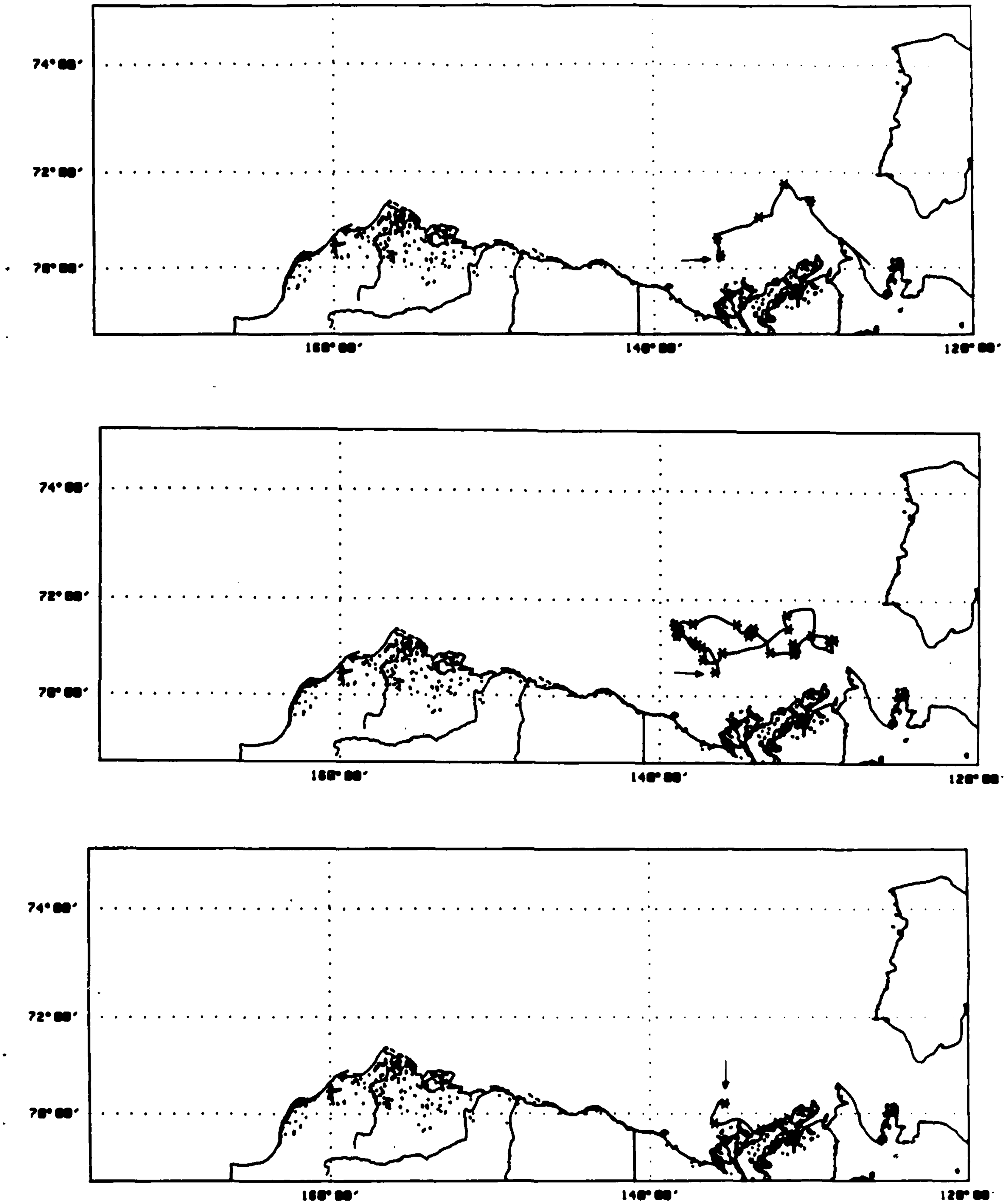
Note: Due to a mix-up with Service ARGOS, buoy positions were not received until 17 AUG 1983 for buoys 4515 through 4520.



FIGURES 4-5a through 4-5c. TRAJECTORIES OF BUOYS 4515, 4517, AND 4518 (1983), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.



FIGURES 4-5d through 4-5f. **TRAJECTORIES OF BUOYS 4519, 4520, AND 4521 (1983), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.**



FIGURES 4-5g through 4-5i. TRAJECTORIES OF BUOYS 4522, 4523, AND 4524 (1983), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.

4.6 1985 Buoys

On 9 August 1985, three buoys were released to the northwest of Prudhoe Bay, Alaska. Buoys 2581 and 4539 immediately began to move towards the west. After approximately one day of movement in this direction they reversed direction and headed east/southeast until they ran aground near Prudhoe Bay on 12 August. Buoy 4538 remained in the area it was deployed for almost a week before it also began to move to the west. After a short time it also reversed direction and ran aground near Prudhoe Bay on 19 August. As all three buoys reversed direction in the same general location, it is believed that an ocean surface front was present which, in concert with local wind shifts, led to the reversal of the direction of these buoys (St. Martin and Lissauer, 1986).

On 25 August, buoy 2581 was recovered by the Alaskan Beaufort Sea Oil Recovery Body (ABSORB) vessel ARCAT and redeployed to the northwest of Prudhoe Bay. This buoy (re-designated 2581a) traversed from east-to-west until it apparently ran aground in early September along the Alaskan coast. Ten days later this buoy apparently broke free and commenced movement toward the east and was tracked (as buoy 2581c) until mid September, 1986 when it ceased transmission. During this movement, it traveled west-to-east into Canadian waters, reversed direction and headed along the southern Beaufort Sea coast past Pt. Barrow, Alaska and into the Chukchi Sea. It remained in the Chukchi Sea, moving first to the southwest along the coast and then to the north/northwest, until it ceased transmission.

Buoy 4538 was recovered near Prudhoe Bay, Alaska on 3 August 1986 by the ARCAT and redeployed to the northwest. It (redesignated as 4538a) moved in various directions until mid November when it ceased transmitting. Overall, however, its movement was away from the Alaska coast.

Table 4-6 provides a summary of these deployments. Trajectories for these buoys are shown as figures 4-6a to 4-6f.

TABLE 4-6

1985 BUOY DATA SUMMARY

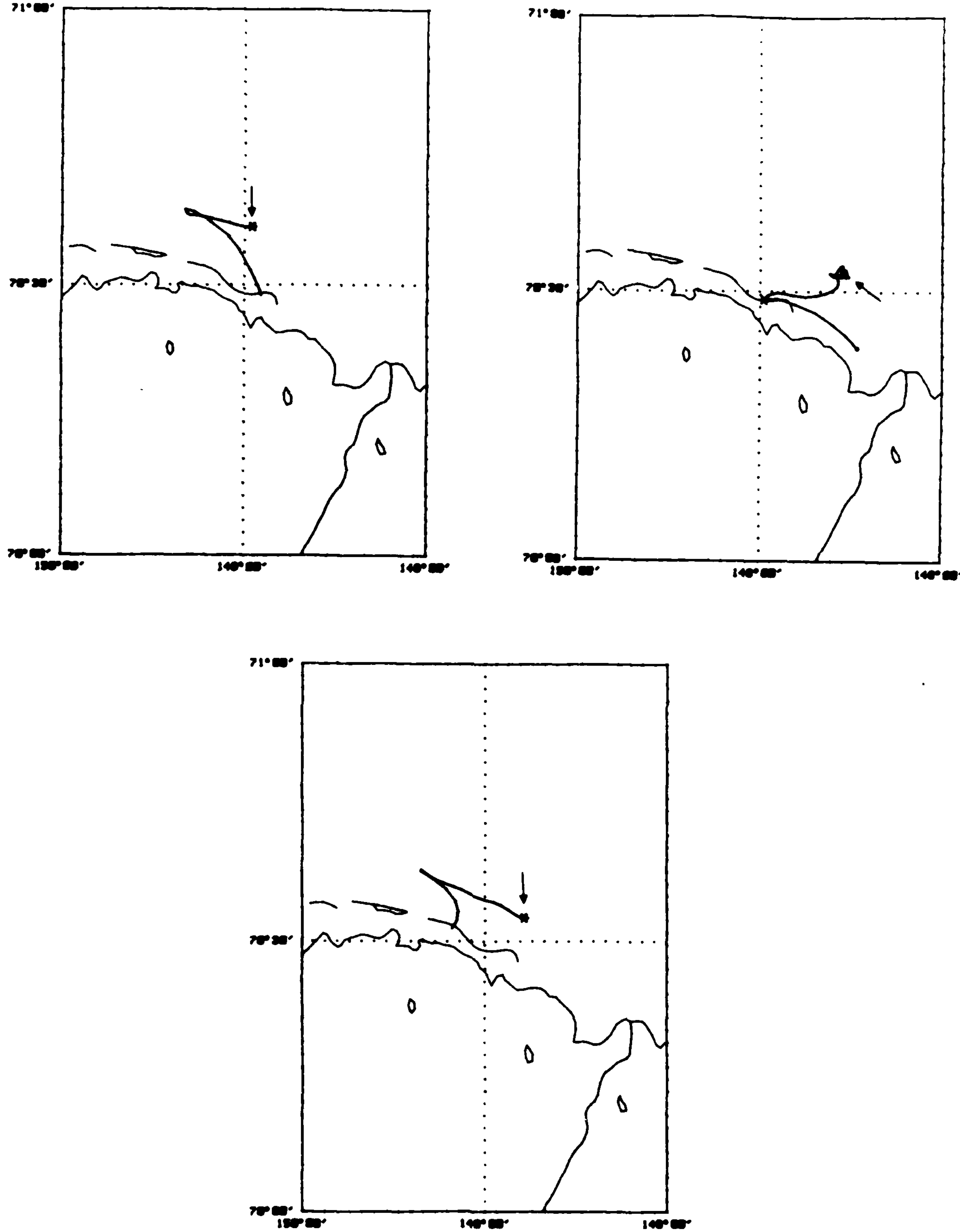
ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	RELEASE DATE	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
2581a	PRL	70-36	148-56	9 AUG 1985	12 AUG 1985
2581b[1]	PRL	70-31	148-20	25 AUG 1985	5 SEP 1985
2581c[2]	PRL	70-54	152-44	15 SEP 1985	10 SEP 1986
4538	PRL	70-33	148-35	9 AUG 1985	19 AUG 1985
4538a[3]	PRL	70-24	148-32	3 AUG 1986	10 NOV 1986
4539	PRL	70-33	148-45	9 AUG 1985	12 AUG 1985

Notes:

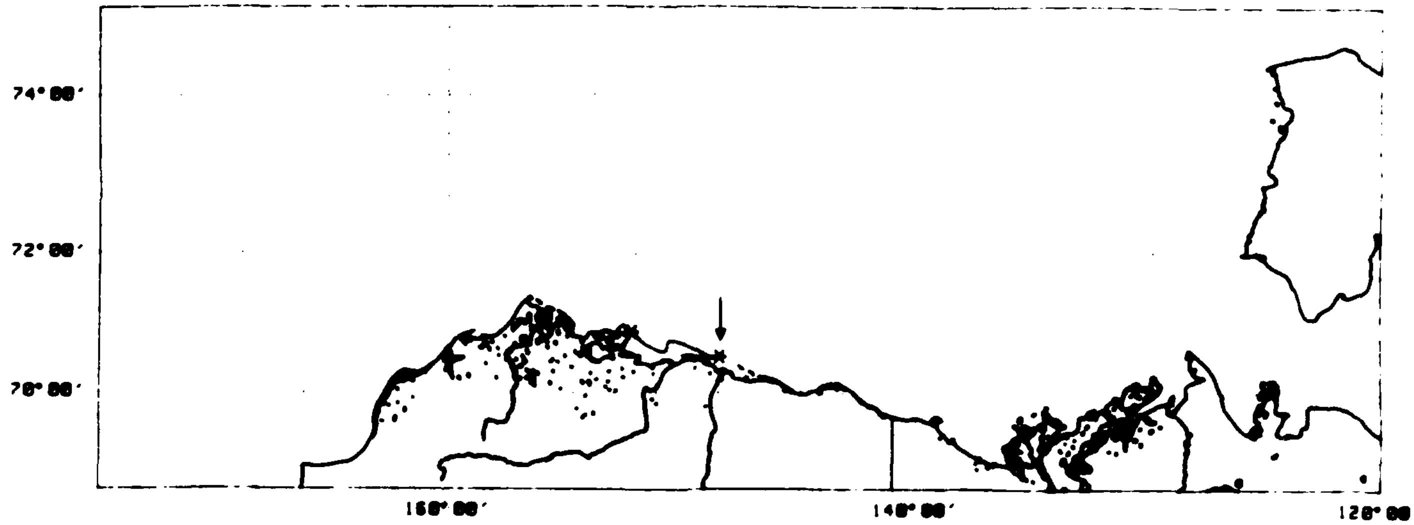
(1) After buoy 2581 ran aground, it was recovered and redeployed. New drift is designated 2581b.

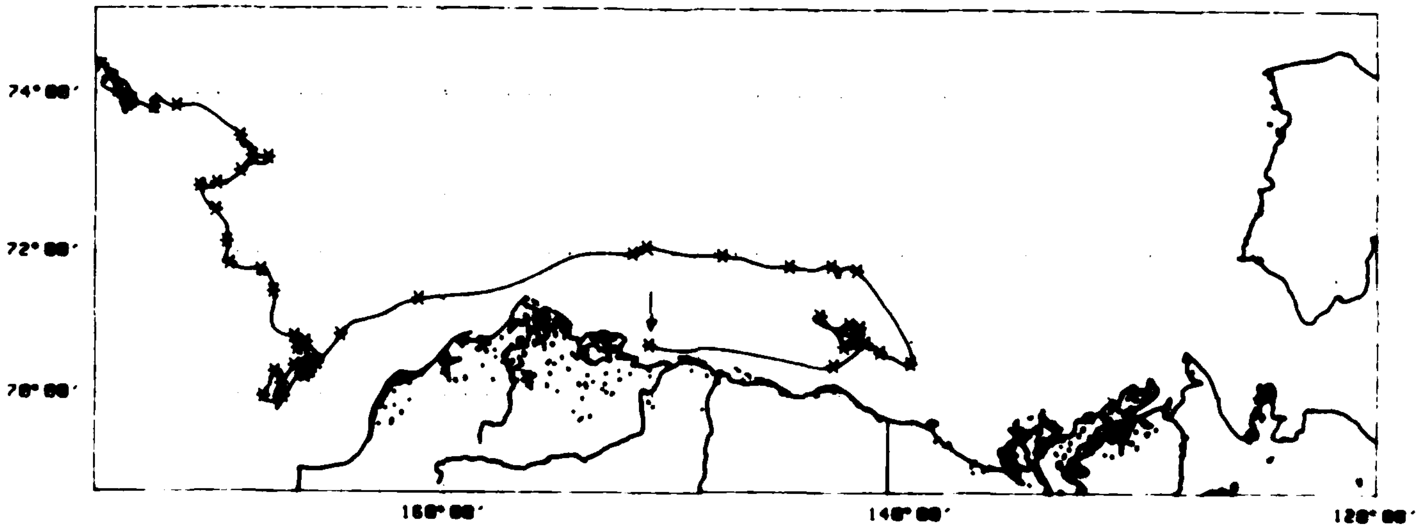
(2) Buoy 2581 ran aground again and floated free after 10 days. Subsequent movement designated 2581c.

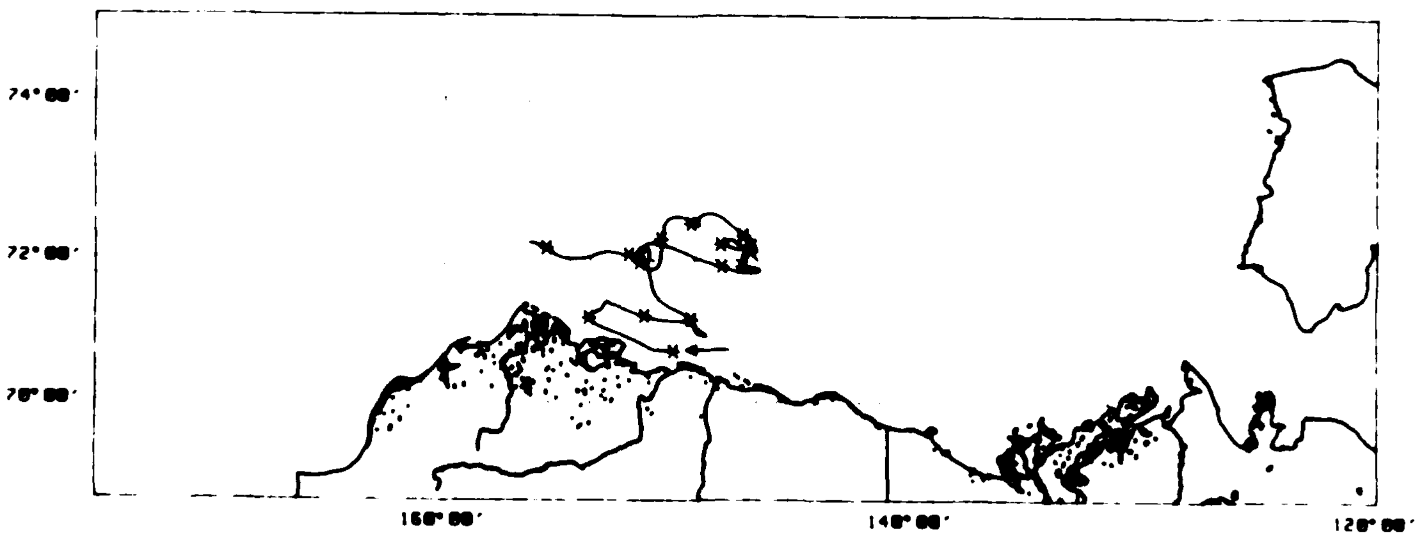
(3) Buoy 4538 was recovered approximately a year after running aground and it was redeployed. Re-designated 4538a.



FIGURES 4-6a through 4-6c. TRAJECTORIES OF BUOYS 2581a, 4538, AND 4539 (1985), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.







FIGURES 4-6d through 4-6f. TRAJECTORIES OF BUOYS 2581b, 2581c, AND 4538a (1985), RESPECTIVELY. EACH ASTERISK REPRESENTS 7 DAYS OF DRIFT.

5.0 RESULTS

5.1 Direction and Speed of Buoys

For buoys in which there were at least 15 data records the direction and speed of each buoy for each data point were determined using a simple two point backward calculation. From this information, histograms of direction and speed and scatterplots of direction versus speed were produced. Scatterplots were only produced if there were at least 150 data records for a buoy. Appendix A contains the histograms of direction and speed while Appendix B contains the scatterplots.

A summary of these calculations is provided as Table 5-1. In general, the average speed of these buoys was under 30 cm/sec and the majority of the movement was along the coast (east/west primarily). Those excursions that were in a more north/south direction were generally of a short duration or of a relatively low speed. As the scatterplots of Appendix B show, the highest speeds were for excursions along the southern Beaufort Sea coast.

5.2 Comparison of Geostrophic Wind to Buoy Drift

Geostrophic winds were calculated for 1979 through 1983. The method used was as follows:

a. Twice daily (0000Z and 1200Z) isobaric charts for 10 meters altitude were obtained from the National Center for Atmospheric Research (NCAR) and used to determine the change in barometric pressure over 5 degrees of latitude (70° N to 75° N) at two locations; 140° W and 160° W.

b. The average of the two differences from step A was determined and used as the average barometric pressure difference for the region covered.

TABLE 5-1

SUMMARY OF BUOYS' SPEED (cm/sec)

YEAR	BUOY ID#	AVERAGE SPEED	AVERAGE u	AVERAGE v	MAXIMUM SPEED
1979	226	14.4	-10.7	-0.3	35.7
	261	13.7	-11.7	5.3	21.0
	404	18.0	-16.6	5.1	22.4
	432	17.9	-15.5	0.1	37.7
	443	15.5	-10.2	-0.2	39.5
1980	2581	11.1	-3.6	1.1	41.6
	2582	6.1	-2.4	0.3	86.4
	2583	2.1	1.4	0.6	11.3
	2587	10.9	-2.7	0.2	61.0
	2589	29.5	16.9	-3.5	92.1
1981	2600	24.9	8.1	-2.3	87.5
	2601	24.4	14.4	-2.2	75.1
	2604	18.4	-6.9	1.6	48.2
	2605	19.9	15.1	-3.0	74.3
	2607	27.2	11.2	-3.4	76.8
	2608	26.0	12.2	-4.6	73.8
1982	4505	12.5	-1.9	-0.9	63.0
	4506	11.8	-6.1	0.6	71.8
	4507	20.1	-5.4	-3.6	48.7
	4508	18.5	-12.1	-1.0	53.5
1983	4515	13.6	12.1	-2.7	47.3
	4517	27.2	24.1	-5.8	114.1
	4518	14.9	13.6	-3.4	34.9
	4519	9.4	1.9	0.1	49.3
	4520	14.2	13.4	-4.5	31.7
	4521	15.7	10.3	-0.7	49.3
	4522	18.9	11.0	-0.4	80.5
	4523	10.9	-0.5	0.5	41.8
	4524	6.1	2.9	-1.1	27.4
1985	2581a	17.6	0.6	-6.0	44.0
	2581b	22.3	-17.5	4.6	75.4
	2581c	11.5	-2.5	-0.2	82.5
	4538	5.9	0.3	-1.6	41.1
	4538a	17.6	-2.6	2.0	55.9
	4539	17.7	-6.7	-0.7	34.6

c. These barometric calculations were inserted into the geostrophic wind equation; W = 0.7*(P/(D*R*F)) where

W = wind speed in cm/sec
P = pressure difference
D = distance between isobars
R = air density (considered constant at 1.225E-3)
F = Coriolis parameter (2*7.292E-5*SIN(Latitude))

The 0.7 factor is to compensate for surface friction when calculating the wind at the surface.

This calculated geostrophic wind represented the U direction only. Although an error was introduced in not rotating the wind vector when bringing it to the surface, its magnitude is so small relative to the error introduced by calculating the wind from isobaric charts as to be insignificant for the purposes of this study.

The calculated values for the U component of the geostrophic wind were compared to the u component of buoys movement over periods when these respective data overlapped. Data which were calculated for these comparisons were; mean U and u, excursions of U and u from their respective mean values, excursions from the mean of u divided by 0.035 (generally, oil on the surface of the ocean is considered to move at 3.5% of the wind speed), cumulative U and u, and cumulative u divided by 0.035. Standard statistical analysis was also performed on this data with the correlation (r) between selected parameters being of the most interest.

These data have been examined to make estimates of three important factors: velocity differences noted between buoy types, use of a mean geostrophic wind as a predictor to buoy movement, and the use of cumulative movements as a predictor. These factors will be discussed in turn.

5.2.1 Variability in Results Due to Buoy Type Differences

Although three different buoy types were used during this experiment, two of these (SIO and PRL) were of similar construction and can be reasonably expected to respond to wind/water forcing similarly. Therefore, only two physical buoy types were compared; the spar type PRL and SIO buoys and the pancake type CANMAR buoys. As the spar style of buoy sits deeper in the water, it is expected that it will move more with the forcing provided by the upper 1 to 2 meters of the water column. The pancake style buoys, being of less draft, are expected to respond to the upper 0.5 meter of water column only. Consequently, it is expected that a difference in buoy movement will be observed between these two types of buoys.

With the data available, there are two possible indicators of differences in movement between buoy types. The first is the percentage of the mean wind speed that each buoy has traveled, on average. The second is the correlation between the cumulative wind (U) and cumulative buoy movement (u). These results are presented as Table 5-2.

The differences which exist between buoy types in the percentage of the mean wind that each buoy drifted are not definitive enough for any conclusions. With the exception of the 1983 buoys, the range in percentages between buoy types were similar. In 1983, all the spar buoys except 4519 had percentage values greater than 2.5 while all the CANMAR buoys had percentages less than 2.0. These differences may be of interest for that year only but generalized conclusions based on percentage values cannot be made.

TABLE 5-2

AVERAGE WIND, AVERAGE BUOY MOVEMENT, CORRELATION VALUES, AND BUOY TYPE

YEAR	BUOY ID#	MEAN U	MEAN u	%	r	TYPE*
1979	226	-362.3	-17.4	4.8	.988	S
	261	-426.0	-11.7	2.7	.989	S
	404	-519.8	-16.3	3.1	.996	S
	432	-189.1	-9.3	4.9	.936	S
	443	-324.6	-13.8	4.3	.996	S
1980	2581	586.3	9.6	1.6	.991	S
	2582	633.5	5.5	0.8	.991	S
	2583	633.5	2.9	0.5	.908	S
	2587	633.5	14.6	2.3	.960	C
	2589	739.1	11.9	1.6	.929	C
1981	2601	19.9	16.0	80.4	.414	S
	2604	-379.2	-7.2	1.9	.806	S
	2605	112.5	16.3	14.4	.813	C
	2607	655.9	10.3	1.6	.941	C
1982	4505	-73.1	-3.2	4.4	.608	C
	4506	-149.8	-15.4	10.3	.707	C
	4507	-150.6	-7.9	5.2	.738	C
	4508	-156.2	-12.7	8.1	.660	C
1983	4515	486.3	15.8	3.2	.955	S
	4517	412.8	23.7	5.7	.989	S
	4518	486.3	16.2	3.3	.995	S
	4519	486.3	5.6	1.2	.978	S
	4520	469.0	11.8	2.5	.923	S
	4521	372.2	6.7	1.8	.529	C
	4522	357.8	4.0	1.1	.415	C
	4523	486.3	1.0	0.2	.270	C
	4524	446.5	5.6	1.3	.688	C

* S - spar, C - CANMAR

The correlation values for the different buoy types during this experiment are of greater interest. In general, the spar type buoys were highly correlated with the wind (cumulative U vs u only) while the CANMAR type buoys were less so. Except for the two spar type buoys in 1981, all of these buoys had correlation values greater than 0.9. Conversely, except for two buoys in 1980 and one buoy in 1981, the CANMAR type buoys all had correlation values less than 0.9, some significantly so. This can be explained by considering the type of wind that is being used for comparison purposes. The calculated geostrophic wind is a large scale wind which is calculated only every twelve hours. Consequently, local short-term winds are not represented by these data. The response of the water to the wind decreases rapidly the deeper one goes in the water column. The response to changes in the wind is also slower as depth increases. As the CANMAR buoys float in the upper 0.5 meters of the water column, it is expected that they will be more responsive to local wind. The spar buoys, which are affected by more water depth are not as responsive to water current changes brought about by small scale local winds. The differences in the correlations which have been found are, therefore, reasonable considering the wind which is being used for these comparisons.

With these differences in mind, any conclusions about the use of satellite tracked buoys to determine surface currents and the use of wind information to predict these currents will need to consider the type of data being collected. The type of buoy as well as the wind's geographic and time scale must be considered when recommending a predictive or tracking technique.

5.2.2 Use of Mean Geostrophic Wind as Predictor

In order for the mean geostrophic wind to be useful as a predictor for buoy movement, the standard error of the mean wind

must be of a small enough magnitude to indicate some steadiness to the wind. If the excursions from the mean are of a magnitude on the order of the mean and if these excursions are highly variable, the mean will not be a good predictive indicator. An analysis of the wind data for the periods that the buoys were operated have shown that, in general, the standard error of the mean was small (10% to 20% of mean value) when the mean wind was greater than 400 cm/sec (Table 5-3).

TABLE 5-3

AVERAGE WIND AND STANDARD ERROR OF MEAN

YEAR	BUOY ID#	MEAN U	STD ERROR
1979	226	-362.3	35.6
	261	-426.0	47.7
	404	-519.8	33.6
	432	-189.1	41.8
	443	-324.6	45.3
1980	2581	586.3	52.3
	2582/83/87	633.5	59.2
	2589	739.1	129.5
1981	2601	19.9	72.7
	2604	-379.2	95.7
	2605	112.5	69.0
	2607	655.9	133.5
1982	4505	-73.1	55.0
	4506	-149.8	51.1
	4507	-150.6	47.9
	4508	-156.2	50.4
1983	4515/18	486.3	36.9
	4517	412.8	47.0
	4519/23	486.3	36.9
	4520	469.0	41.3
	4521	372.2	88.5
	4522	357.8	58.0
	4524	446.5	48.6

For mean wind values less than 400 cm/sec, the standard error of the mean becomes relatively much greater indicating that the geostrophic wind is more variable. Under these circumstances, the use of the mean as a predictor is more suspect and not considered to be reliable. Even under circumstances in which the mean wind is greater than 400 cm/sec, the use of the mean as a predictor is not without substantial error. The mean values presented in Table 5-3 are for time periods of several weeks to several months duration. Under these circumstances, the mean is a reliable indication of the long term average in the overall magnitude of the wind in the U direction. Consequently, as seen in Table 5-2, if the mean wind is positive (wind to the east) the mean buoy movement in the u direction is also positive. Conversely, if the mean wind is negative (wind to the west), the mean buoy movement is also negative (u direction). For situations in which at least two weeks of wind data has been collected/calculated it is possible to estimate the mean (+/- u) direction, although not magnitude, of a drifting buoy. However, if the wind data is not of a long enough term to average over several storm cycles, a calculated mean may be skewed by short term wind events. Under these circumstances the mean is not reliable and cannot be used to estimate long term buoy drift direction.

5.2.3 Cumulative Values of Wind and Buoy Drift

The cumulative wind and buoy drift speeds for each buoy and its respective wind were calculated and analyzed to determine the correlation coefficient (r) in each case (Table 5-2). As previously discussed, for spar type buoys the correlations were generally quite high (> 0.9) and indicated a directional response of these buoys to the large scale wind. The high correlation, although an indicator of trend, does not measure relative

magnitude. As can be seen in Table 5-2, those buoys with correlation values greater than 0.9 have mean drift rates ranging from 0.5% to 5.7% of the mean wind speed. Plots of cumulative distance (cumulative speed times time over which speed was calculated) versus time for these buoys are given as Figure 5-1a to 5-5e. Note that, for all these comparisons, a negative distance indicates cumulative movement to the west while a positive distance is cumulative movement eastward.

In 1979, the cumulative wind indicates a relatively steady U component out of the east. Figures 5-1a and 5-1b are plots of the cumulative wind (standardized to cumulative distance in 1000's of kilometers) versus the cumulative u-direction speed divided by .035 (also standardized) of each buoy. Figure 5-1a depicts this comparison for buoys 261 and 404. As shown, the curves for the buoys are quite close to that for the wind. Figure 5-1b, which shows buoys 226, 432, and 443 also shows a similarity to these curves with the exception that buoy 226 has a higher cumulative distance. This indicates, that for this year, the buoys are responding quite closely to the effect of the large scale geostrophic wind over a time frame approaching 9 weeks.

In 1980, the cumulative wind also indicates a somewhat steady wind. However, for this period, the U component of the wind is generally from the west. The comparison for buoy 2581 is shown as Figure 5-2a and indicates a similarity in direction and in steadiness. This buoy is drifting at slower than 3.5% of the wind speed, though. Figure 5-2b is the comparison for buoys 2582, 2583, 2587, and 2589. All four buoys indicate a similarity in direction. However, buoys 2582 and 2583 are drifting at a slower rate than 3.5% of the wind while buoy 2587 drifted opposite the winds direction for 2 days. Otherwise, this buoy did drift at close to 3.5% of the wind and buoy 2589, though of short duration, also followed closely to the winds forcing.

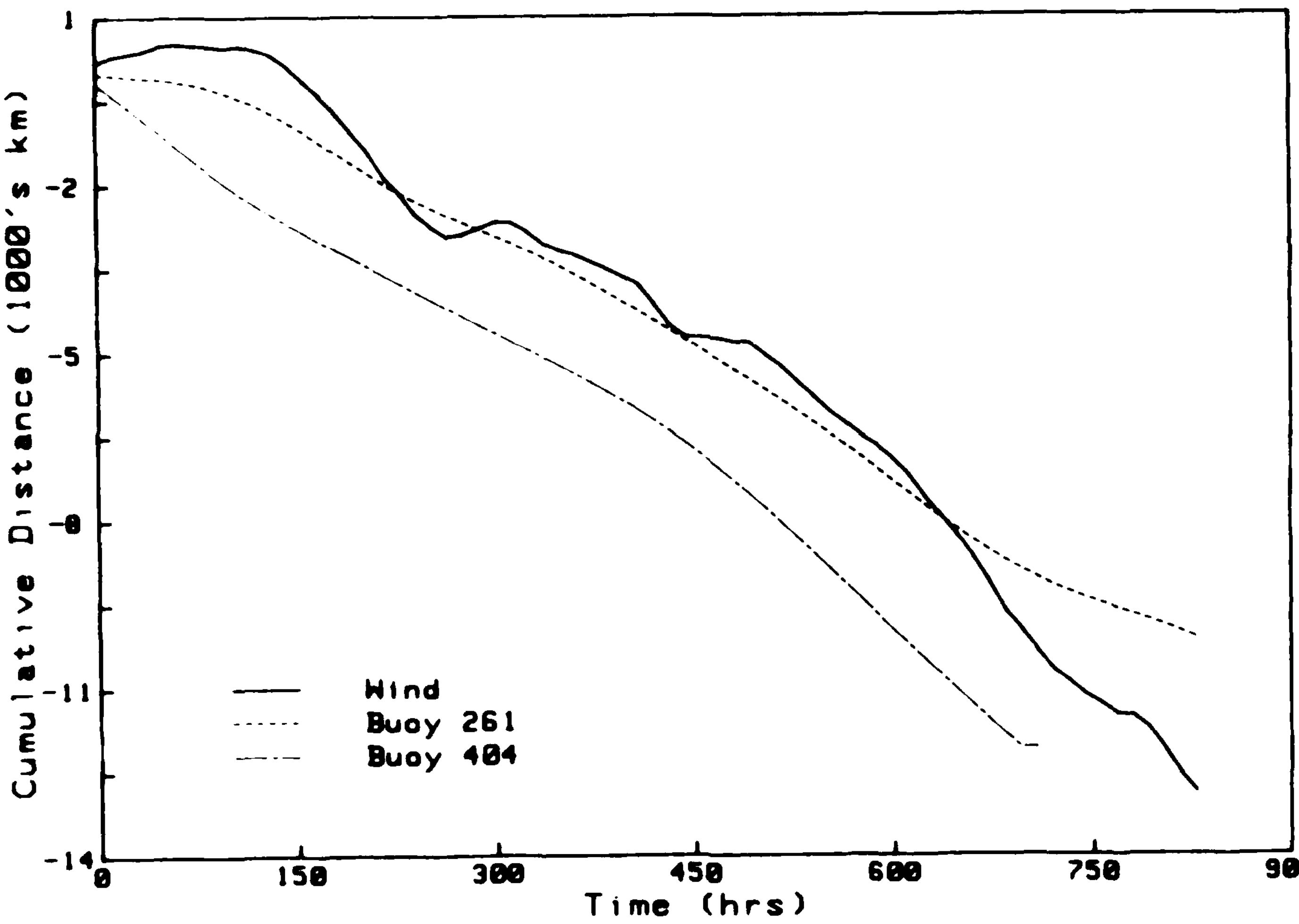


FIGURE 5-1a. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 261 AND 404 (1979)

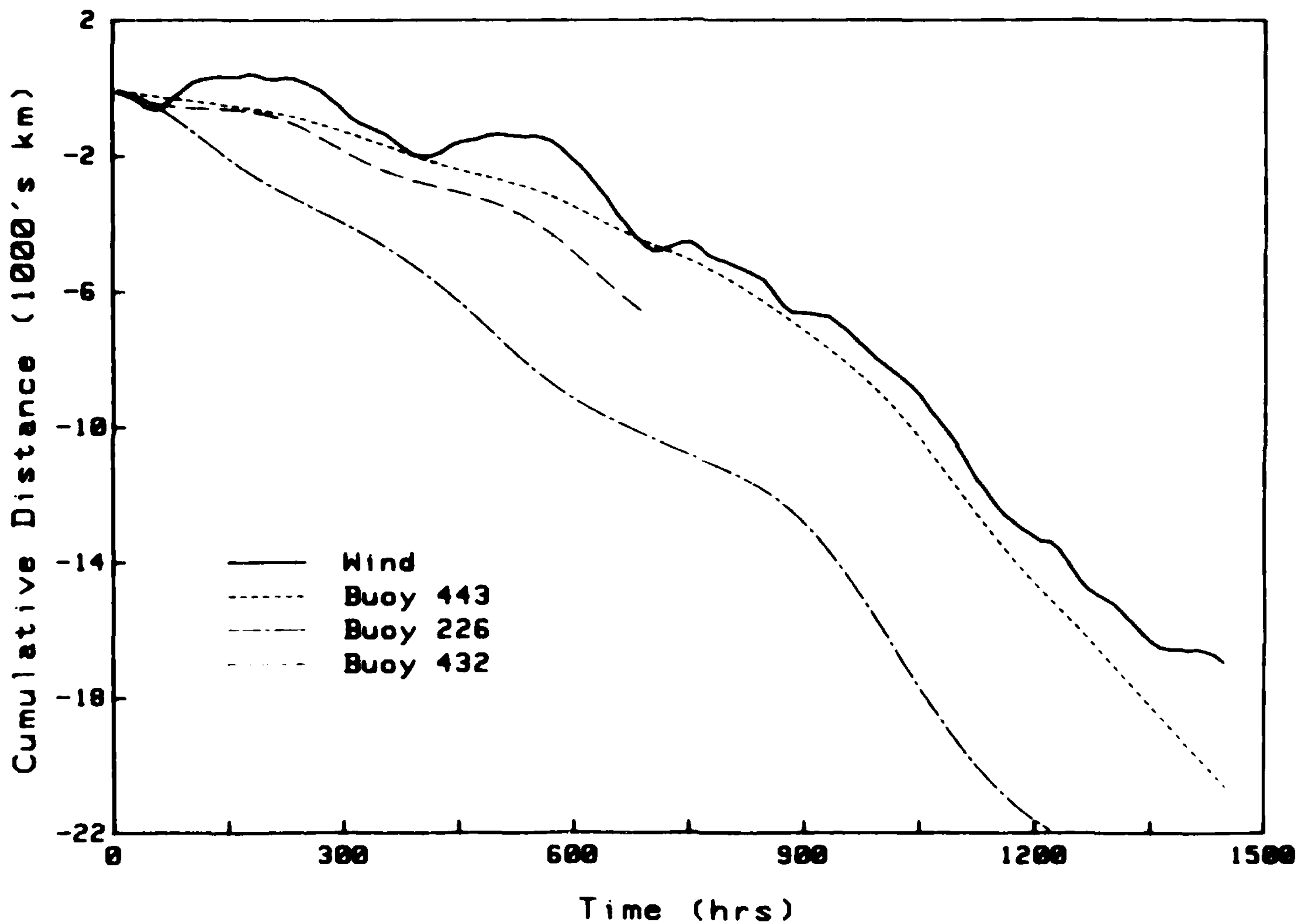


FIGURE 5-1b. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 226, 432, AND 443 (1979)

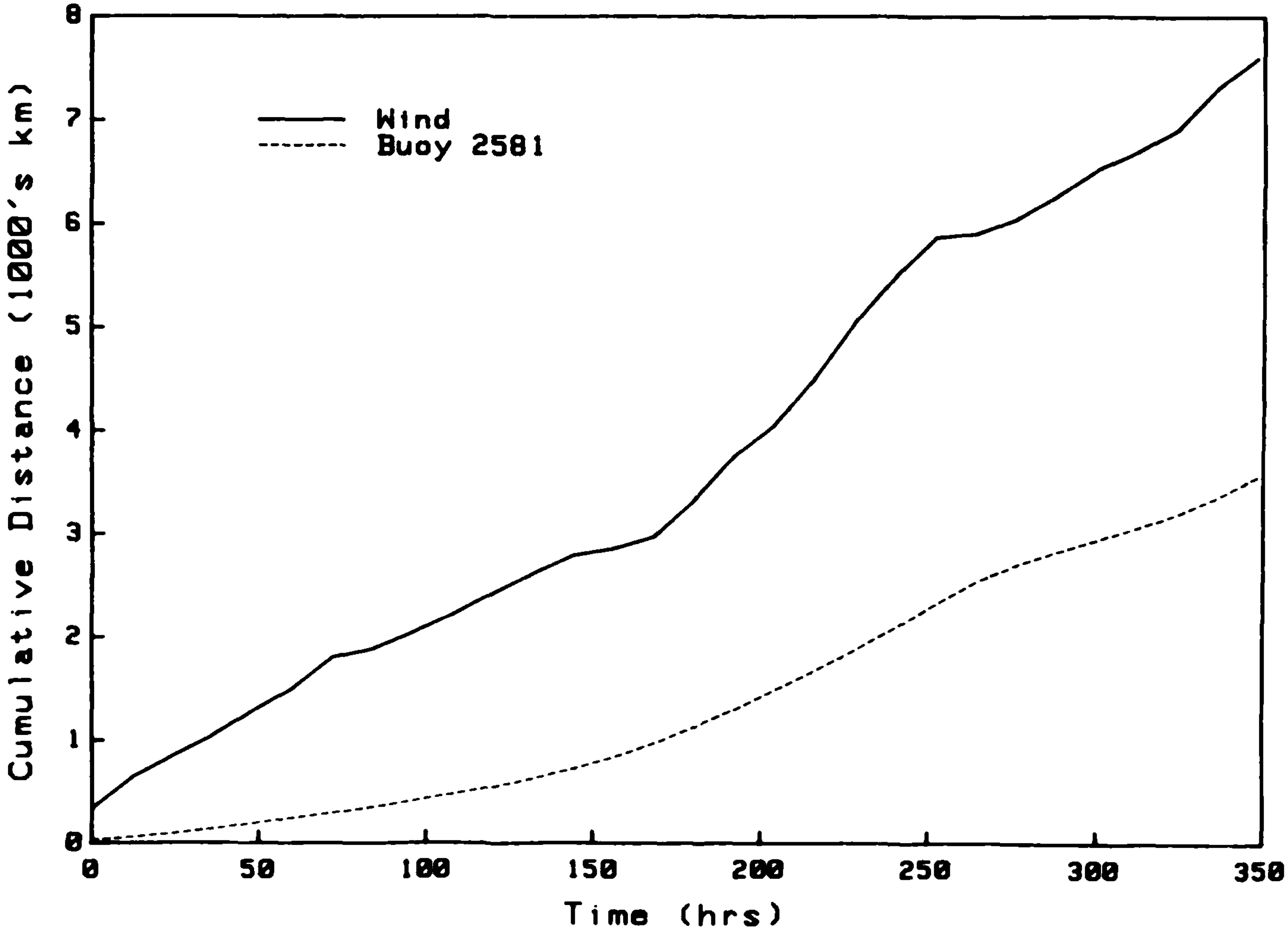


FIGURE 5-2a. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOY 2581 (1980)

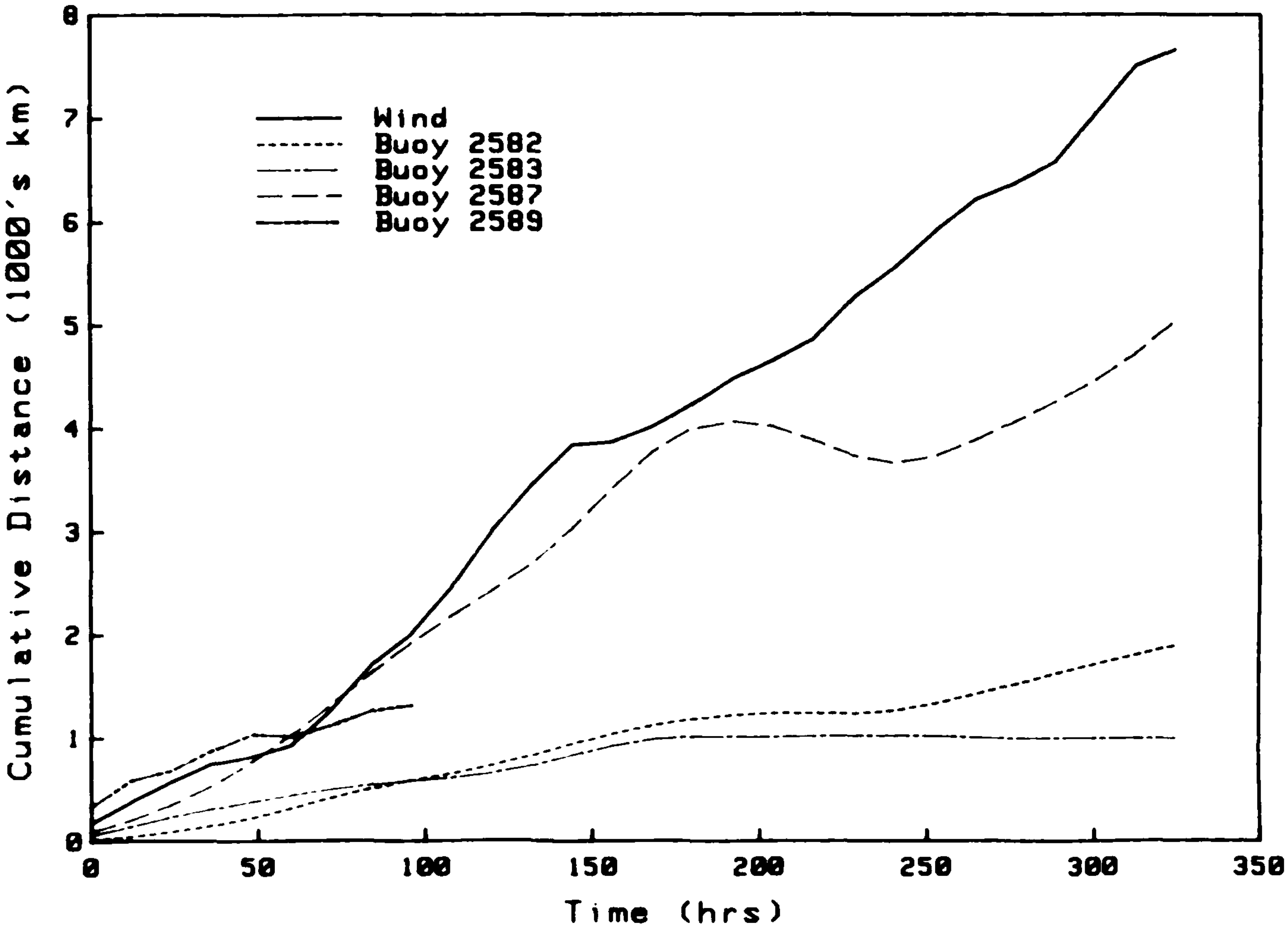


FIGURE 5-2b. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 2582, 2587, AND 2589 (1980)

For 1981, the wind was much more variable as can be seen by Figures 5-3a to 5-3c. Figure 5-3a indicates that the wind was initially from the west (1 day), near zero for 3 days, from the west again for 1 day and finally from the east. The two buoys whose drift records corresponded to this period (2601 and 2605) moved steadily eastward until near the end of their records when they were nearly aground. For the time period in which buoy 2604 was drifting (Figure 5-3b) the wind was also quite variable. For the first 3 days, it came steadily form the east then shifted direction for 2 days and repeated this reversal at two day intervals. Interestingly, buoy 2604 followed this wind pattern quite closely with no apparent time lag, though at a lower speed than 3.5% of the wind. The final buoy from 1981 which was compared is 2607 (figure 5-3c). For this period, the wind was fairly steady from the west. Except for the initial day of buoy 2607's drift, it followed the wind fairly close though at less than 3.5% of the wind. The initial drift opposite the wind may have been due to other factors such as concentrations of ice or river input.

During 1982, the wind was variable as seen by the relative spikiness of the cumulative wind on Figure 5-4. Buoys 4505, 4506, 4507 all generally drifted to the west. Even when the wind reversed direction for a short time and settled into a week of very low speeds (hours 400 to 700 on Figure 5-4), these buoys still drifted generally westward. It was not until near the end of their respective position records that they reversed direction for a few days. Buoy 4505 drifted quite differently from the other three buoys. Initially, it also drifted to the west (8 days). This buoy then reversed direction and drifted generally eastward for the remainder of its movement. No reliable data is available to account for the difference in its trajectory as compared to the other buoys.

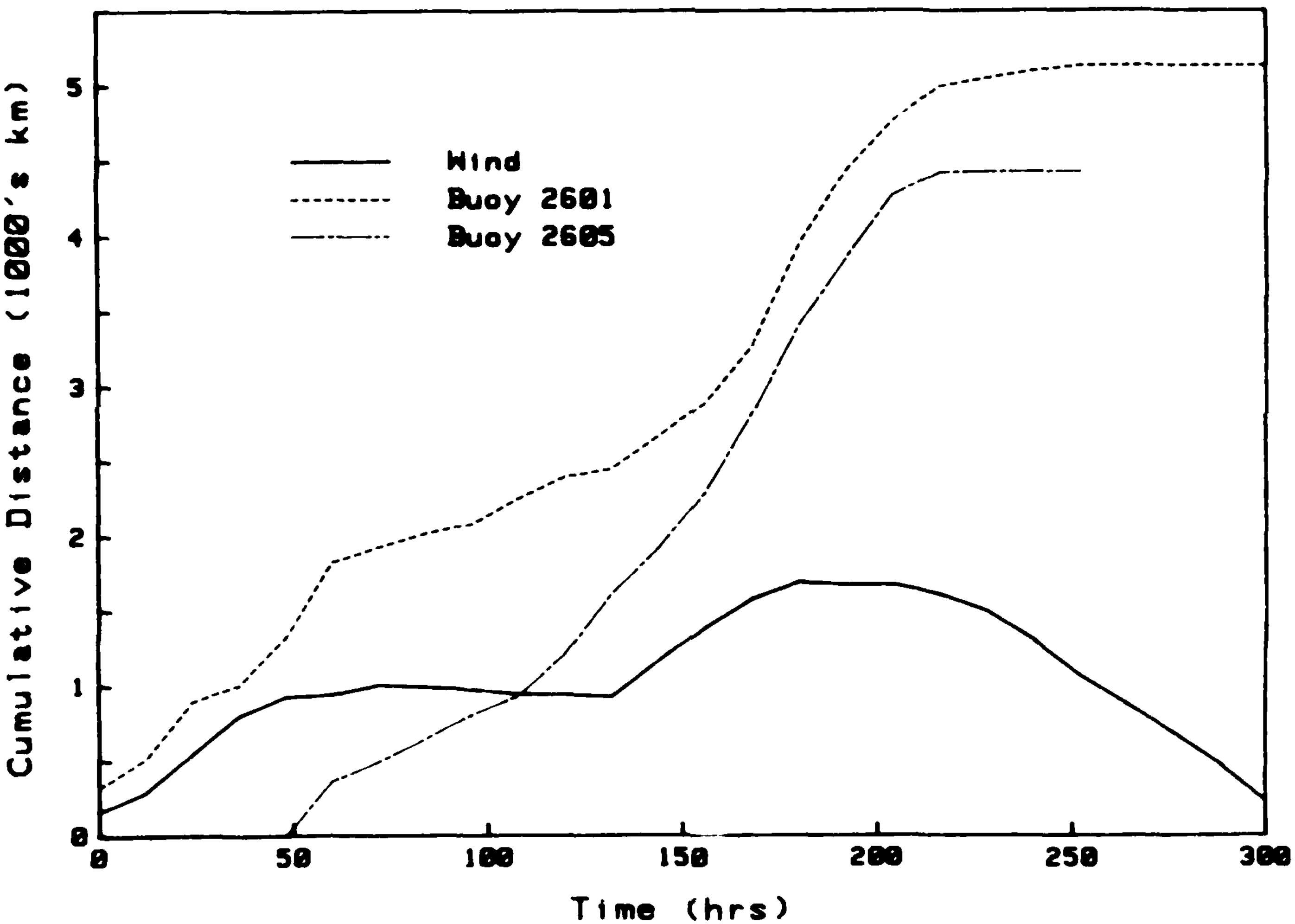


FIGURE 5-3a. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 2601 AND 2605 (1981)

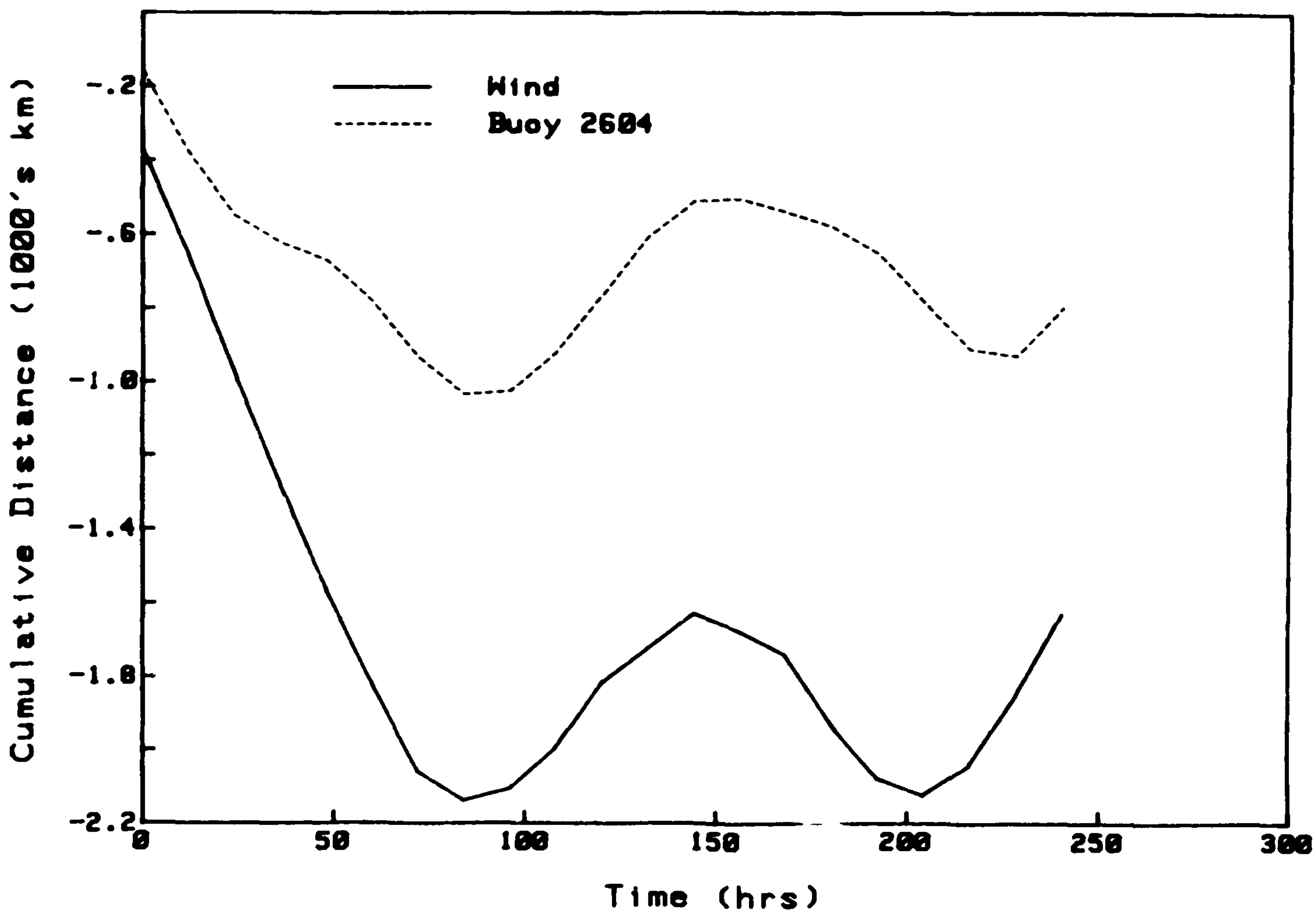


FIGURE 5-3b. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOY 2604 (1981)

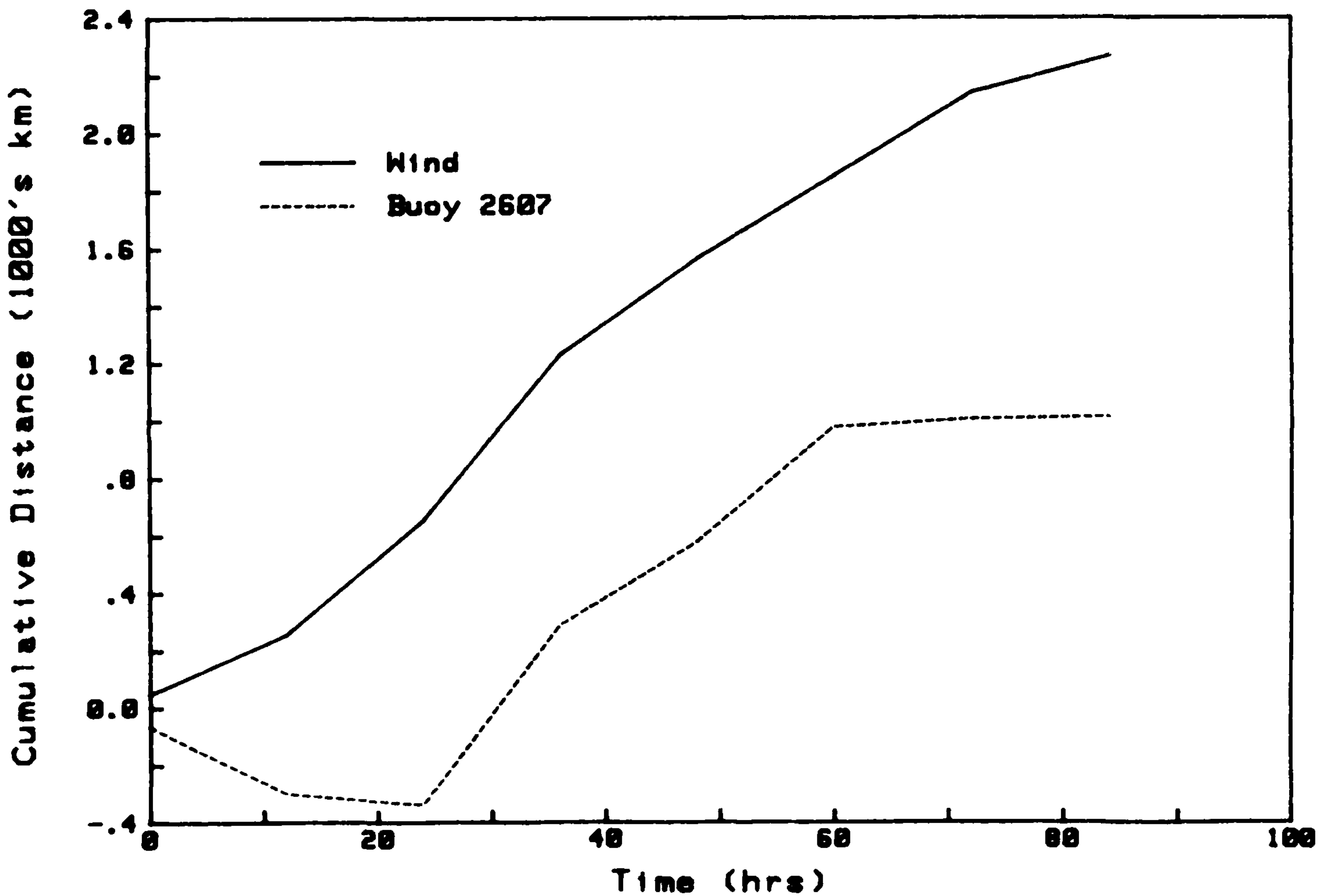


FIGURE 5-3c. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOY 2607 (1981)

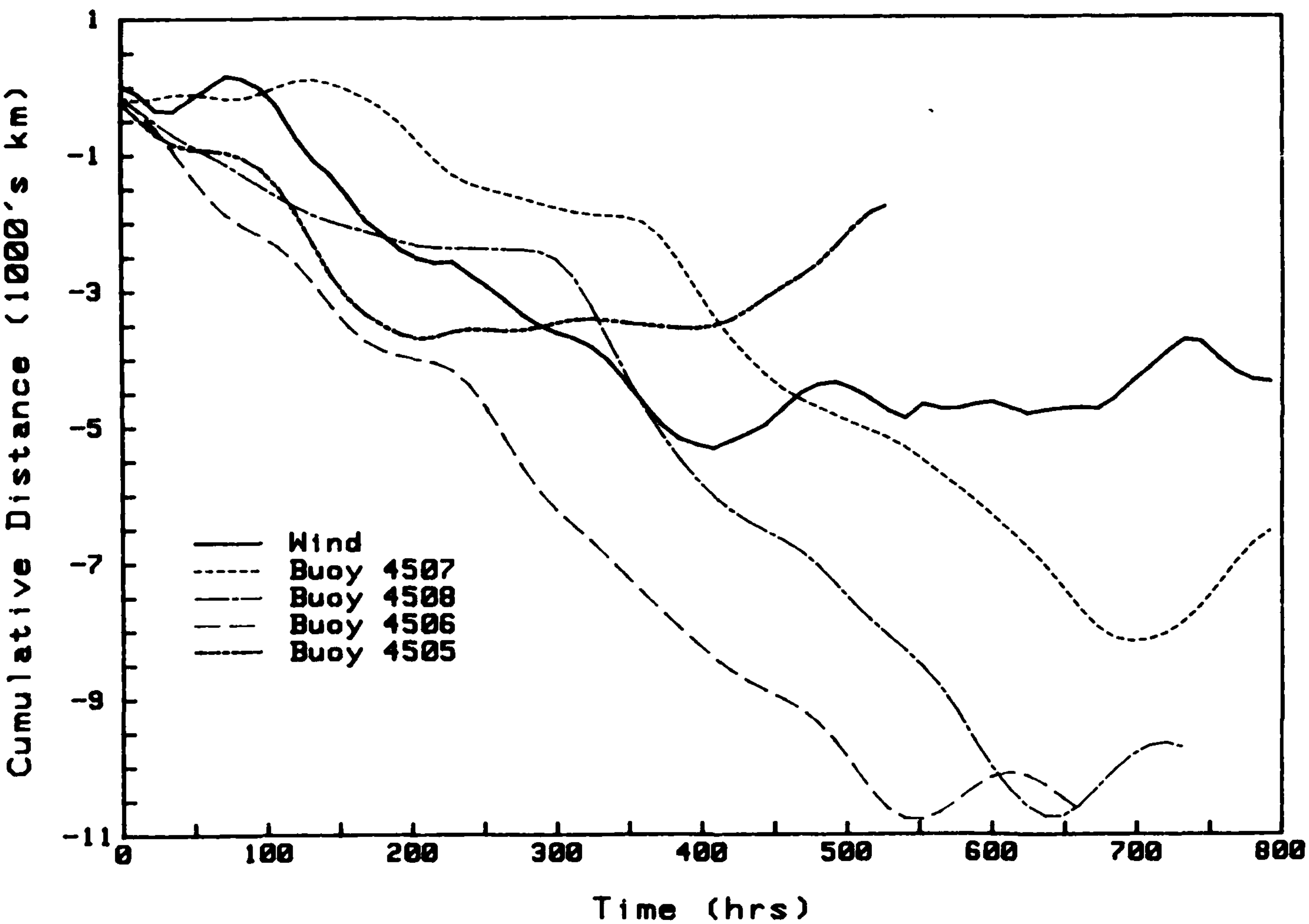


FIGURE 5-4. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 4505, 4506, 4507, AND 4508 (1982)

The cumulative wind for 1983 indicates that the wind was generally steady from the west. Figures 5-5a through 5-5e are the comparisons for the buoys deployed during that year. Buoy 4515 (Figure 5-5a) and buoys 4517 and 4520 (Figure 5-5b) drifted very close to the forcing from the wind. Their speed, although not exactly 3.5% of the wind speed, was very close. Buoys 4521 and 4522 (Figure 5-5c), buoys 4519 and 4523 (Figure 5-5d), and buoy 4524 (Figure 5-5e) did not respond to the wind as well. Initially, they drifted opposite the wind and their overall trajectories indicate a much slower movement than 3.5% of the wind speed. Buoy 4518 (Figure 5-5d) was most closely coupled to the forcing from the wind. Its cumulative distance is nearly identical to that of the wind in both slope and magnitude.

This analysis has shown that under circumstances of steady winds, buoys tend to drift in the general direction that the wind is blowing. By calculating the cumulative wind over a several day period, it may be possible to estimate the general direction of the surface current which is responding to the wind. As the majority of the buoys examined drifted at a speed which was less than 3.5% of the wind speed, yet not consistent from buoy to buoy, an estimate of speed is not considered practical.

5.3 Comparison of Drift Between Selected Buoys

At certain times, buoys were released within close time and spacial proximity. A comparison of the drift of these buoys has been performed in order to determine the variability in the forcing on these buoys. The buoys in which this situation occurred are: 1979 - buoys 226, 432, and 443 and buoys 261 and 404; 1980 - buoys 2582, 2583, and 2587; 1981 - buoys 2600 and 2607, and buoys 2601 and 2605; 1983 - buoys 4515 and 4517, and buoys 4518, 4519, and 4520; 1985 - buoys 2581a, 4538a, and 4539. The comparison used was the horizontal separation of buoy pairs

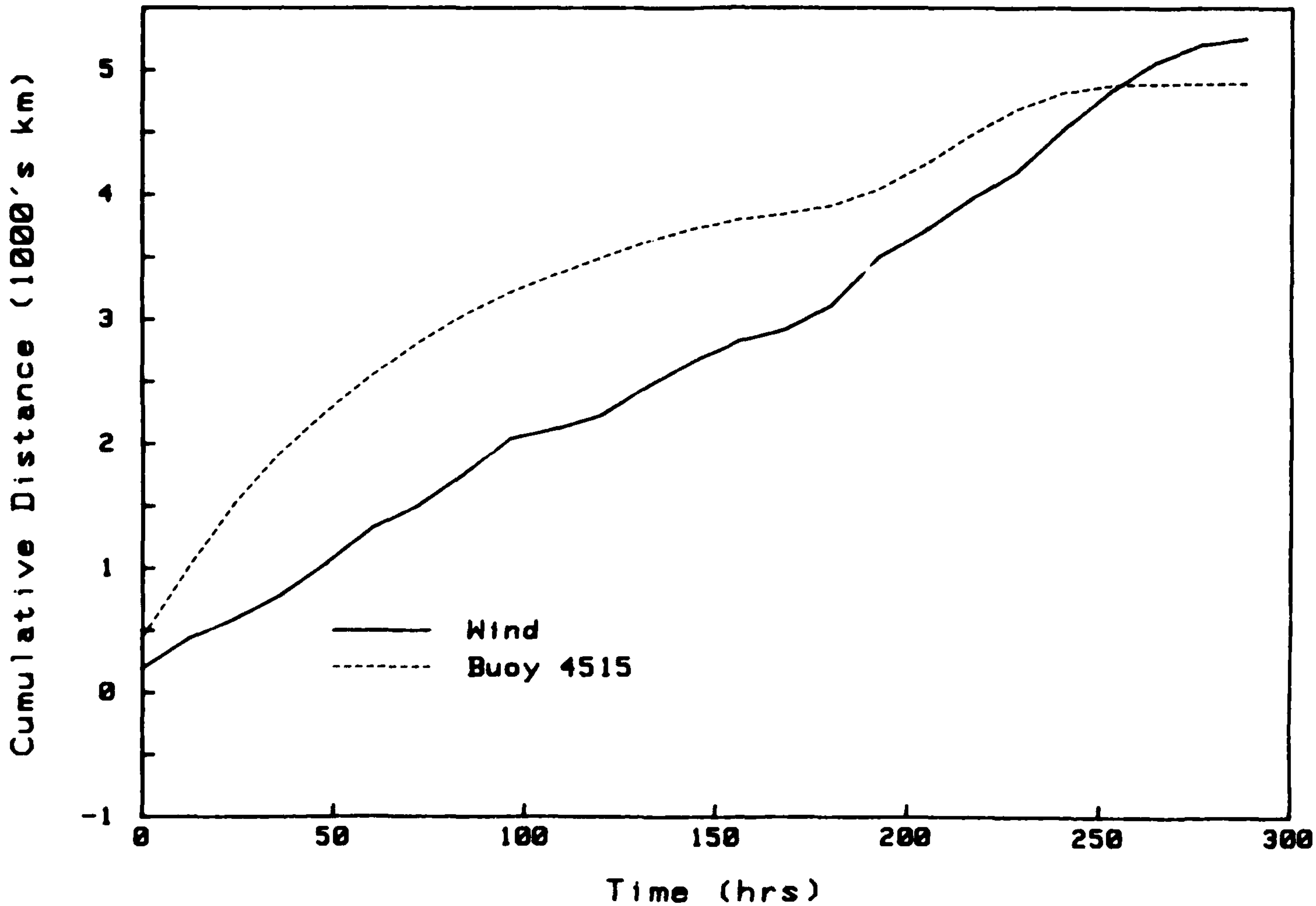


FIGURE 5-5a. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOY 4515 (1983)

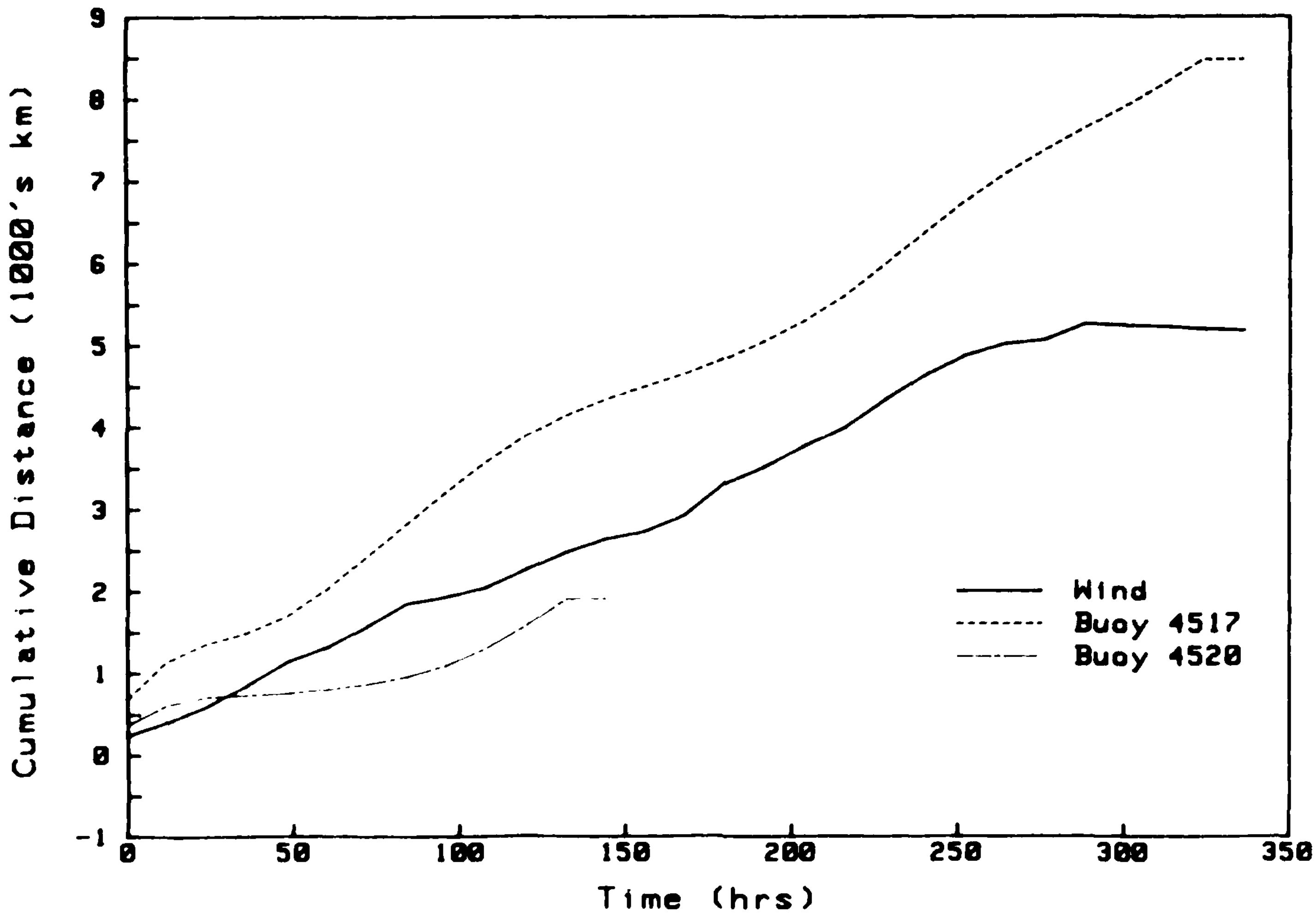


FIGURE 5-5b. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 4517 AND 4520 (1983)

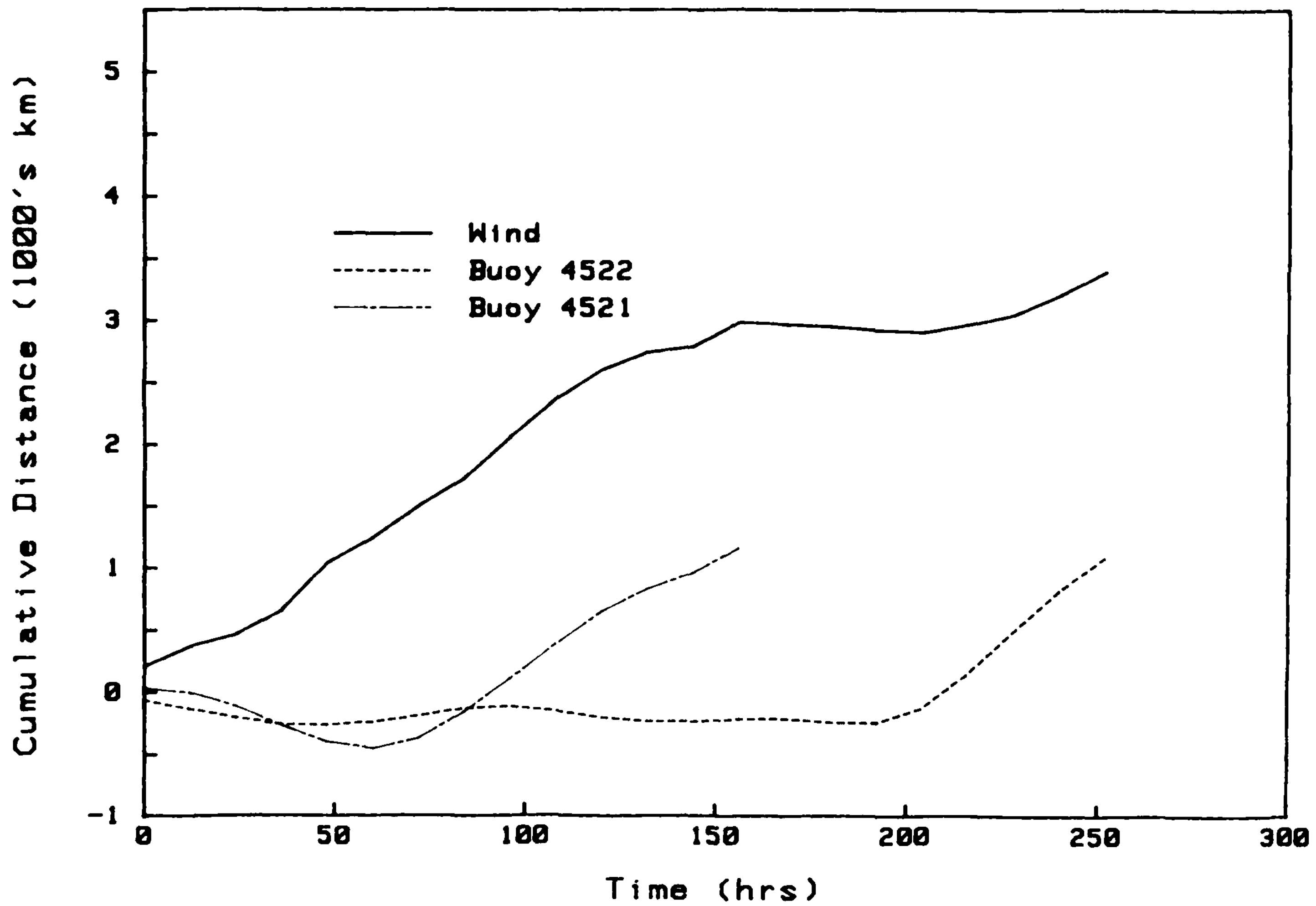


FIGURE 5-5c. **CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOYS 4521 AND 4522 (1983)**

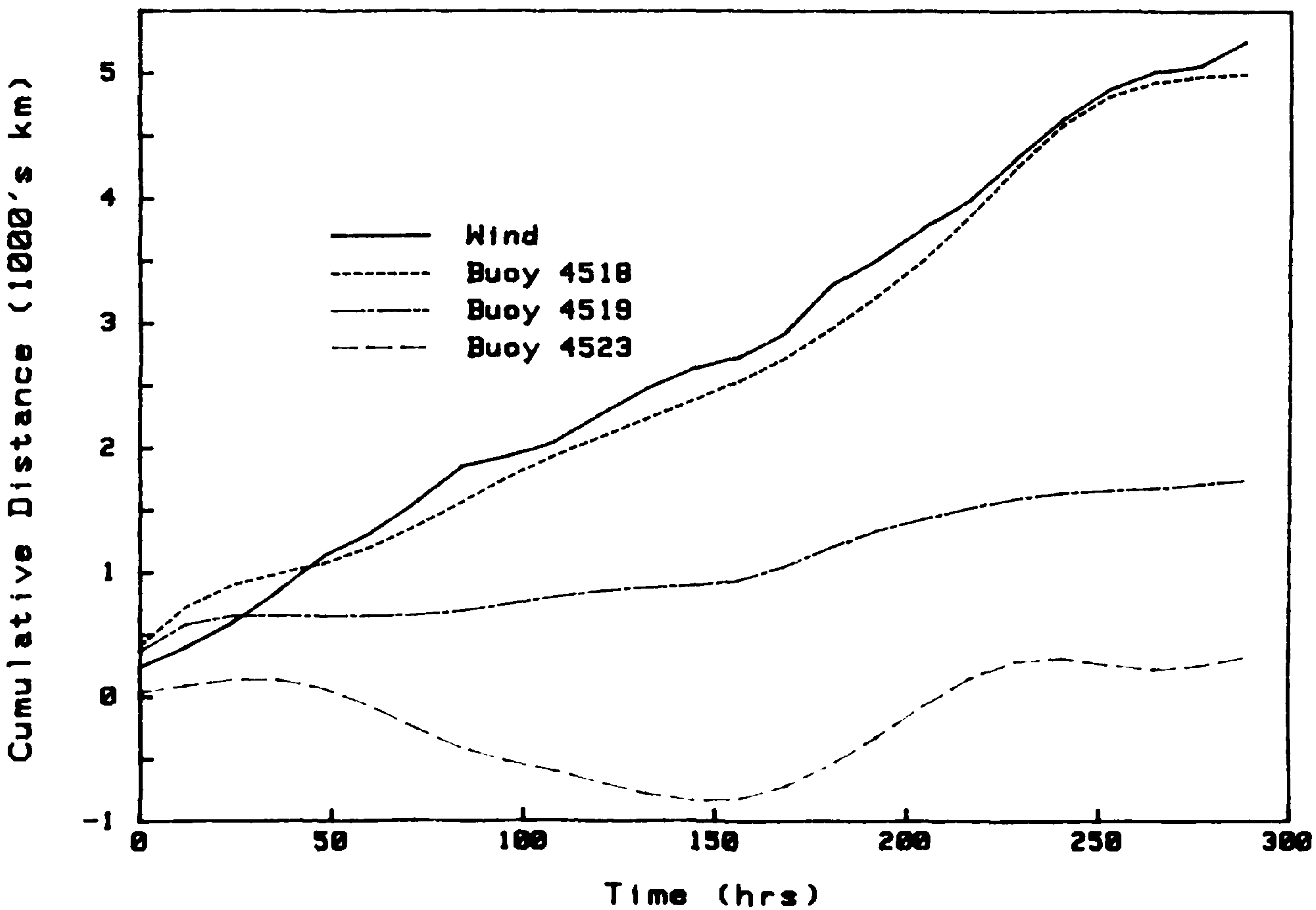


FIGURE 5-5d. CUMULATIVE DISTANCE OF U COMPONENTS OF THE GEOSTROPHIC WIND AND OF BUOYS 4518, 4519, AND 4523 (1983)

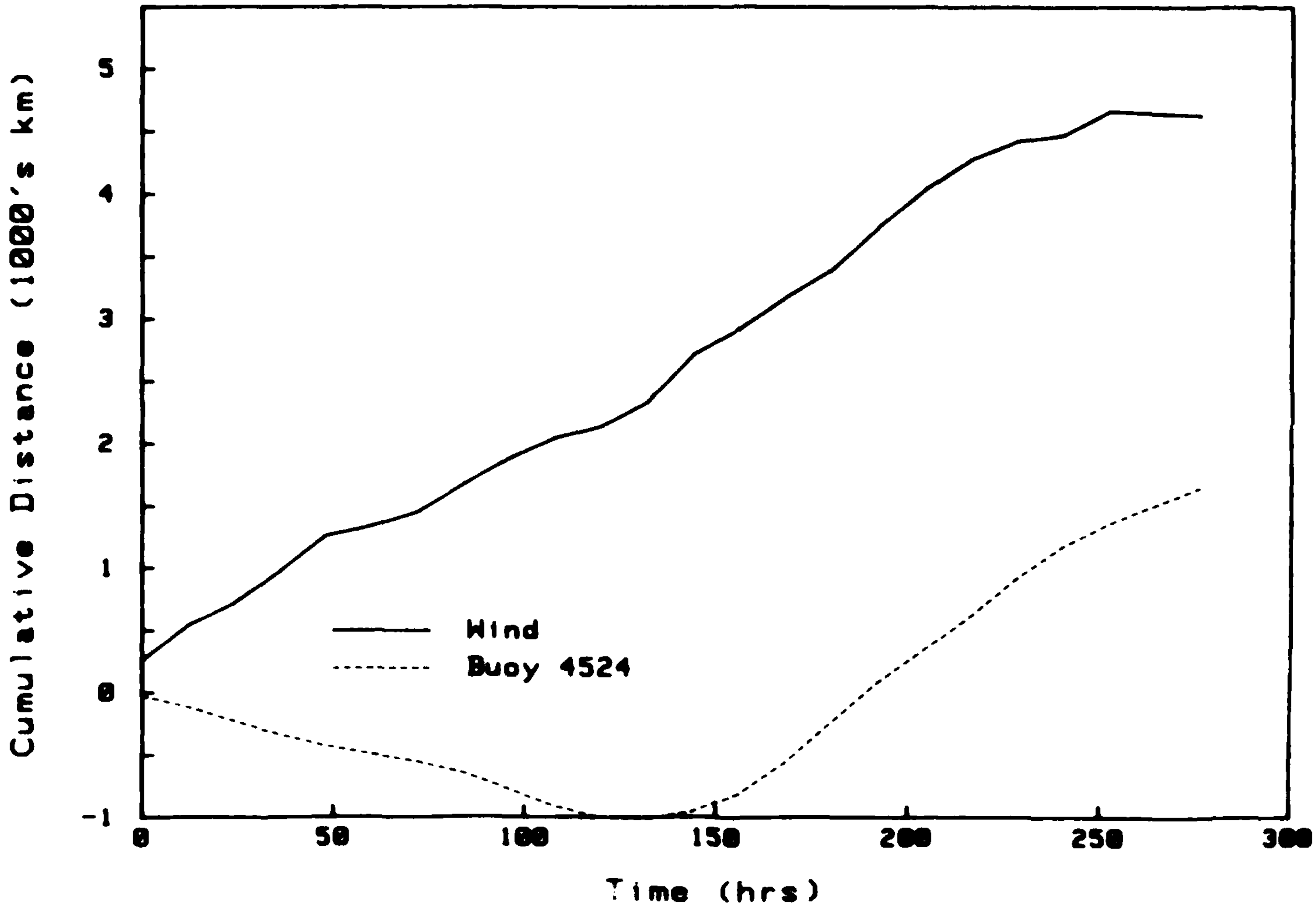


FIGURE 5-5e. CUMULATIVE DISTANCE OF U COMPONENT OF THE GEOSTROPHIC WIND AND OF BUOY 4524 (1983)

over time. If the forcing on a pair of buoys is similar, one would expect that the separation of the buoys will not vary much with time. Therefore, if the correlation coefficient between time and buoy separation is low (< 0.5), the possibility of similar forcing is greater than if the correlation is high (> 0.7). The comparison of buoy pairs is presented by order of year of buoy release.

5.3.1 Horizontal Separation - 1979 Buoys

Four buoy pairs were examined from 1979 to determine if similar forcing could be hypothesized. Table 5-4 lists the correlation coefficients of buoy separation versus time for these buoy pairs.

TABLE 5-4

Correlation Coefficients for 1979 Buoy Pairs

Buoy Pair	r
226-432	.779
226-443	-.264
432-443	.905
261-404	.551

The buoy pairs 226-432 and 432-443 have high correlation coefficients indicating that the separation between these pairs was generally increasing over time. This is indicative of differences in forcing on each buoy in these pairs (note that the buoy pair 226-443 has a low correlation coefficient). The forcing differences could be due to variations in local winds, topography, ice concentration, or river input. Since adequate data to resolve these aspects are not available, it is only possible to make broad assumptions about variations in forcing between buoys within a pair.

The buoy pair 226-443 had a low correlation coefficient while buoy pair 261-404 has a coefficient which is slightly above

0.5. This implies that the forcing on the buoys in these pairs may be similar. In order to better determine whether this is the case, an examination of a plot of separation versus time for each pair was conducted (see Figures 5-6a and 5-6b). For buoy pair 226-443, the separation between these buoys increased rapidly during the first 3 weeks. For the next 6 weeks, the separation was more constant (at 150 km) which indicates similar forcing was affecting these buoys. At that time, the separation changed rapidly for 3 weeks until a steady separation of 50 km existed for the final 3 1/2 weeks of the record. Although there were periods in which the forcing on these buoys was quite different, the periods of somewhat constant separation indicates that, for these periods, the total forcing that existed to drive these buoys was very similar. For the other buoy pair (261-404, figure 5-6b), the separation between these buoys was somewhat constant (at approximately 10-15 km) for the first 3 weeks of drift. After that time, the separation rapidly increased for the remainder of the record. This indicates that the forcing on these buoys was similar during the first three weeks of their drift.

Overall, no definitive statement about the relative forcing on the buoys which were deployed in 1979 can be made. Under some circumstances, similar forcing mechanisms appeared to be present. However, the overall force on these buoys was different enough to cause variability in their trajectories.

5.3.2 Horizontal Separation - 1980 Buoys

Of the buoys deployed during 1980, three buoy pairs were examined to determine the variability in their horizontal separation over time. Table 5-5 lists these buoy pairs and the correlation values for separation versus time.

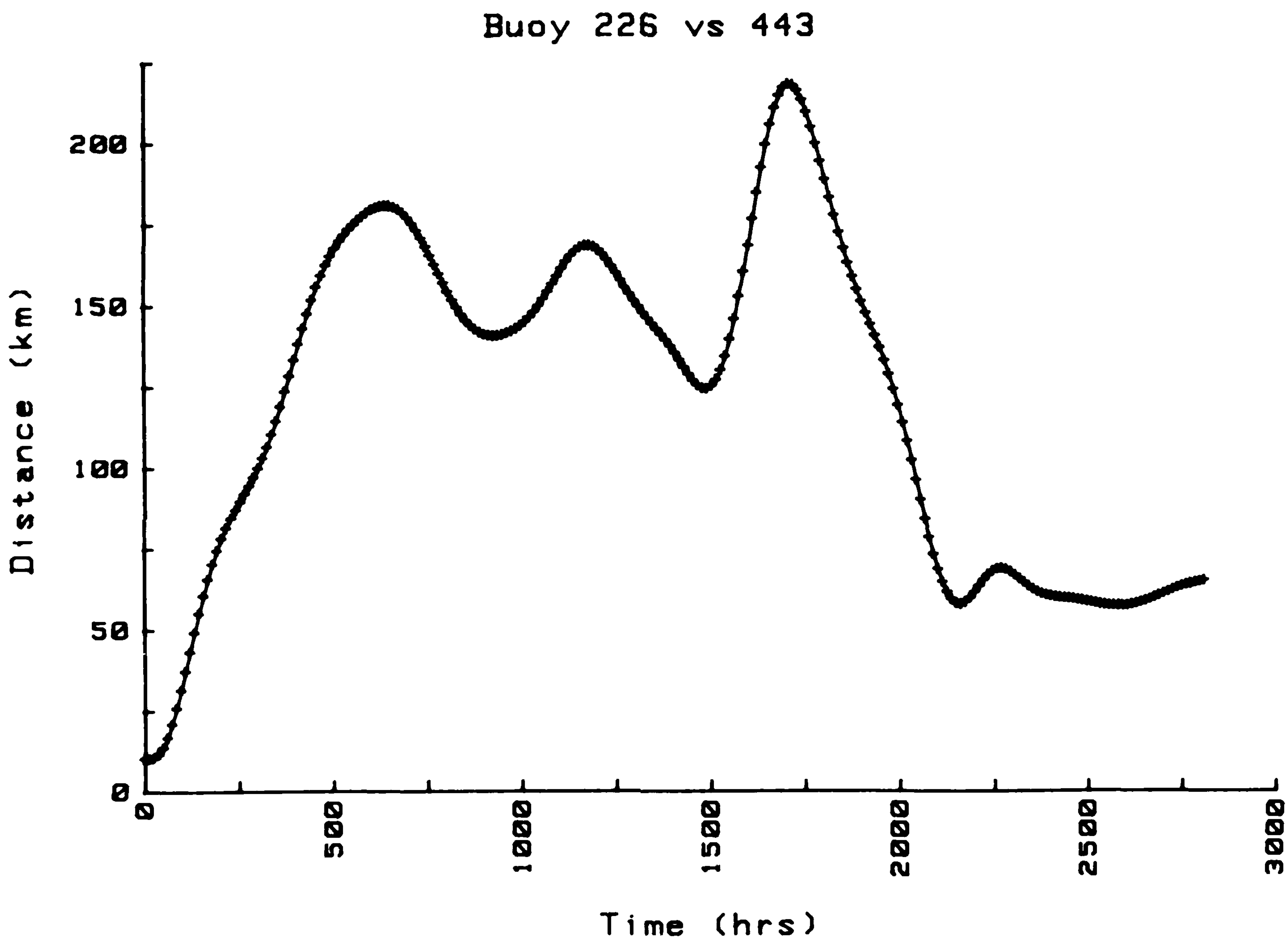


FIGURE 5-6a. SEPARATION BETWEEN BUOYS 226 AND 443 (1979) VERSUS TIME

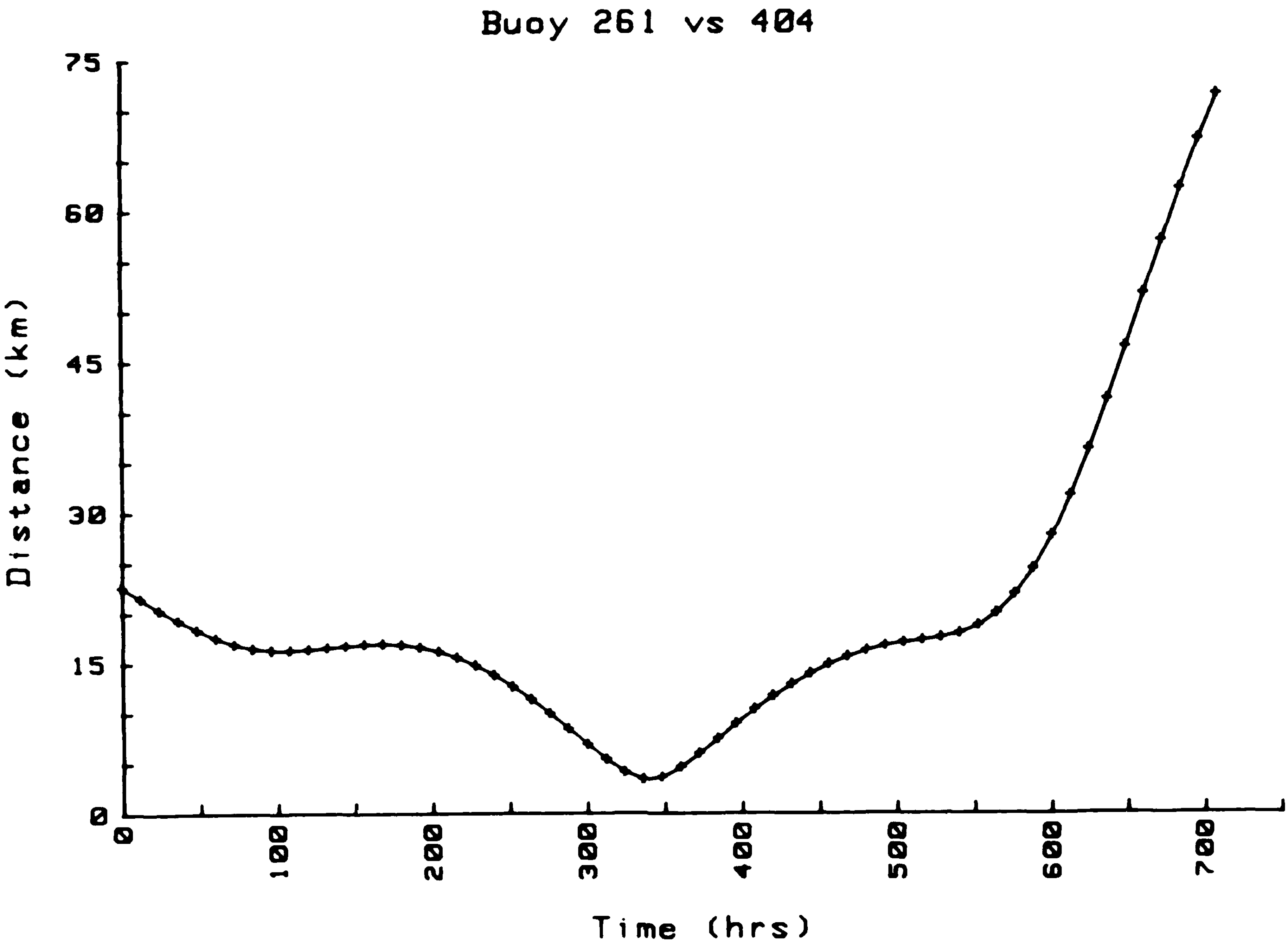


FIGURE 5-6b. SEPARATION BETWEEN BUOYS 261 AND 404 (1979) VERSUS TIME

TABLE 5-5

Correlation Coefficients for 1980 Buoy Pairs

Buoy Pair	r
2582-2583	.773
2582-2587	-.409
2583-2587	.959

As can be seen in Table 5-5, only buoy pair 2582-2587 has a low correlation coefficient. The other two buoy pairs have high coefficients indicating that the forcing on these buoys was dissimilar. Figure 5-7 is a plot of the separation between buoys 2582 and 2587 versus time. As shown, the separation between these buoys rapidly increased to about 260 km during the first 5 weeks of drift. The separation over time was relatively more steady during the next 9 weeks (varying from 200 km to 270 km) until the distance between these buoys rapidly increased to 320 km then decreased to 150 km during a two week period. Relative steadiness in the separation was observed again during the remainder of the record (a 10 week period). Although there were some periods of relatively similar forcing on these two buoys, the overall analysis for 1980 indicates that the forcing was quite variable for all three buoy pairs.

5.3.3 Horizontal Separation - 1981 Buoys

For the 1981 buoy releases, two buoy pairs were examined. They are listed in Table 5-6 along with the correlation coefficients for separation versus time for each pair.

TABLE 5-6

Correlation Coefficients for 1981 Buoy Pairs

Buoy Pair	r
2600-2607	.647
2601-2605	-.443

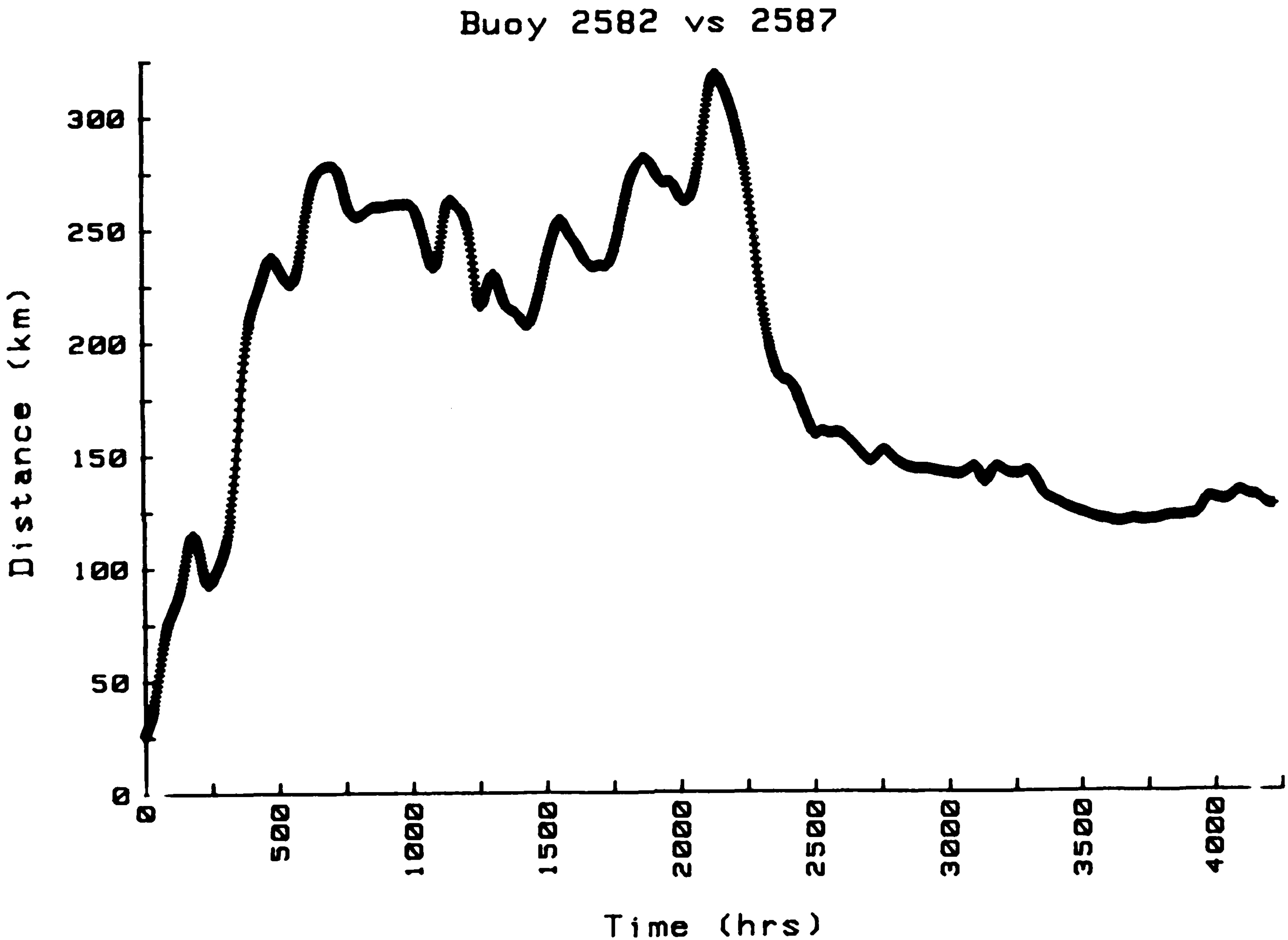


FIGURE 5-7. SEPARATION BETWEEN BUOYS 2582 AND 2587 (1980) VERSUS TIME

Although the correlation coefficient for the buoy pair 2600-2607 is less than 0.7, it is not of a low enough value to indicate that similar forcing may have existed on these buoys. The other buoy pair (2601-2605) has a coefficient which is low enough to warrant further examination. Figure 5-8 is a plot of the horizontal separation of these buoys over time. As is shown, the separation did vary over time to a large degree. However, since the separation first rapidly increased then began an overall decrease, the correlation coefficient was less than 0.5. As can be seen by this figure, though, the forcing on these buoys is not similar. Consequently, the available data for 1981 indicates a variability in the forcing on the buoys released.

5.3.4 Horizontal Separation - 1983 Buoys

Of the buoys released in 1983, four buoy pairs were analyzed. They are listed in Table 5-7 along with the correlation coefficients for horizontal separation versus time for each pair.

TABLE 5-7

Correlation Coefficients for 1983 Buoy Pairs

Buoy Pair	r
4515-4517	.947
4518-4519	-.316
4518-4520	.785
4519-4520	.813

For the 1983 buoy deployments, only one buoy pair has a low enough correlation coefficient to warrant further investigation. Figure 5-9 compares the horizontal separation of buoys 4518 and 4519 over time. As with the comparison of buoys 2601 and 2605, the low correlation for this pair does not indicate a steadv separation distance. What actually occurred was these buoys

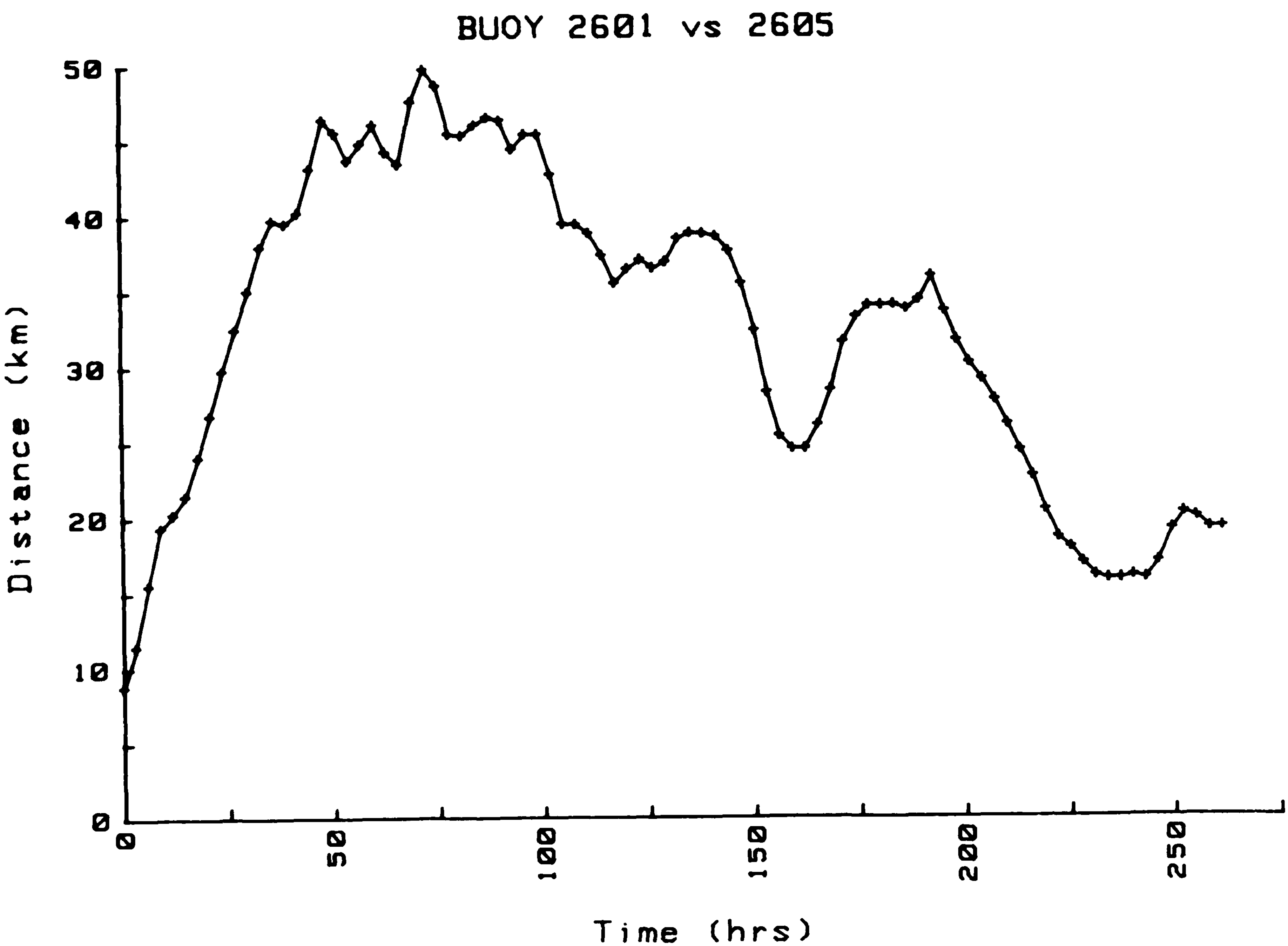


FIGURE 5-8. SEPARATION BETWEEN BUOYS 2601 AND 2605 (1981) VERSUS TIME

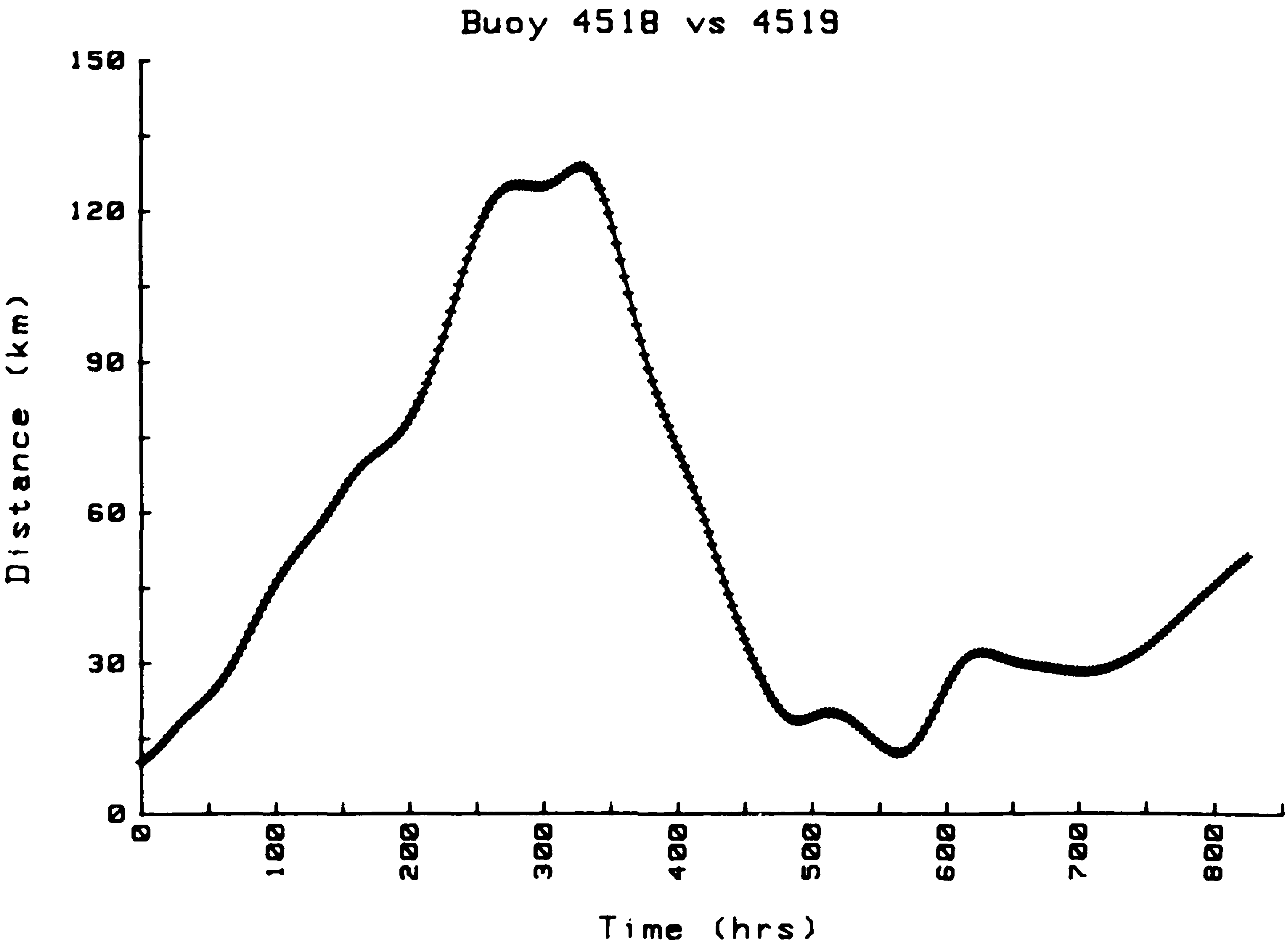


FIGURE 5-9. SEPARATION BETWEEN BUOYS 4518 and 4519 (1983) VERSUS TIME

first rapidly separated, then moved closer together before beginning another period of increase in the separation distance. Consequently, the forcing on these, and the other buoys examined in 1983, varied from buoy to buoy.

5.3.5 Horizontal Separation - 1985 Buoys

The three initial buoy releases in 1985 were conducted during a 4 hour period with the distance between buoys at release of approximately 10 km. The three buoy pairs that were examined and their respective correlation coefficients for horizontal separation versus time are listed as Table 5-8.

TABLE 5-8

Correlation Coefficients for 1985 Buoy Pairs

Buoy Pair	r
2581a - 4538	-.285
2581a - 4539	-.181
4538 - 4539	.775

The correlation coefficients for two of these buoy pairs is low enough to suggest further examination. Plots of separation versus time for both these pairs are given as Figures 5-10a and 5-10b. Again, in both these cases, the low correlation values are due to these buoys moving either together (2581a vs 4539) or apart (2581a vs 4538) and then reversing the trend of separation. The low correlation value is not due to similarities in the forcing on the buoys in each pair but is due to a reverse in the trend of the forcing. Since the third buoy pair (4538-4539) has a high correlation coefficient, the forcing which acted on these three buoys was dissimilar even though they were deployed in close time and spacial proximity to each other. One possible reason for the differences in the forcing was presented in St. Martin and Lissauer (1986). To summarize the findings in

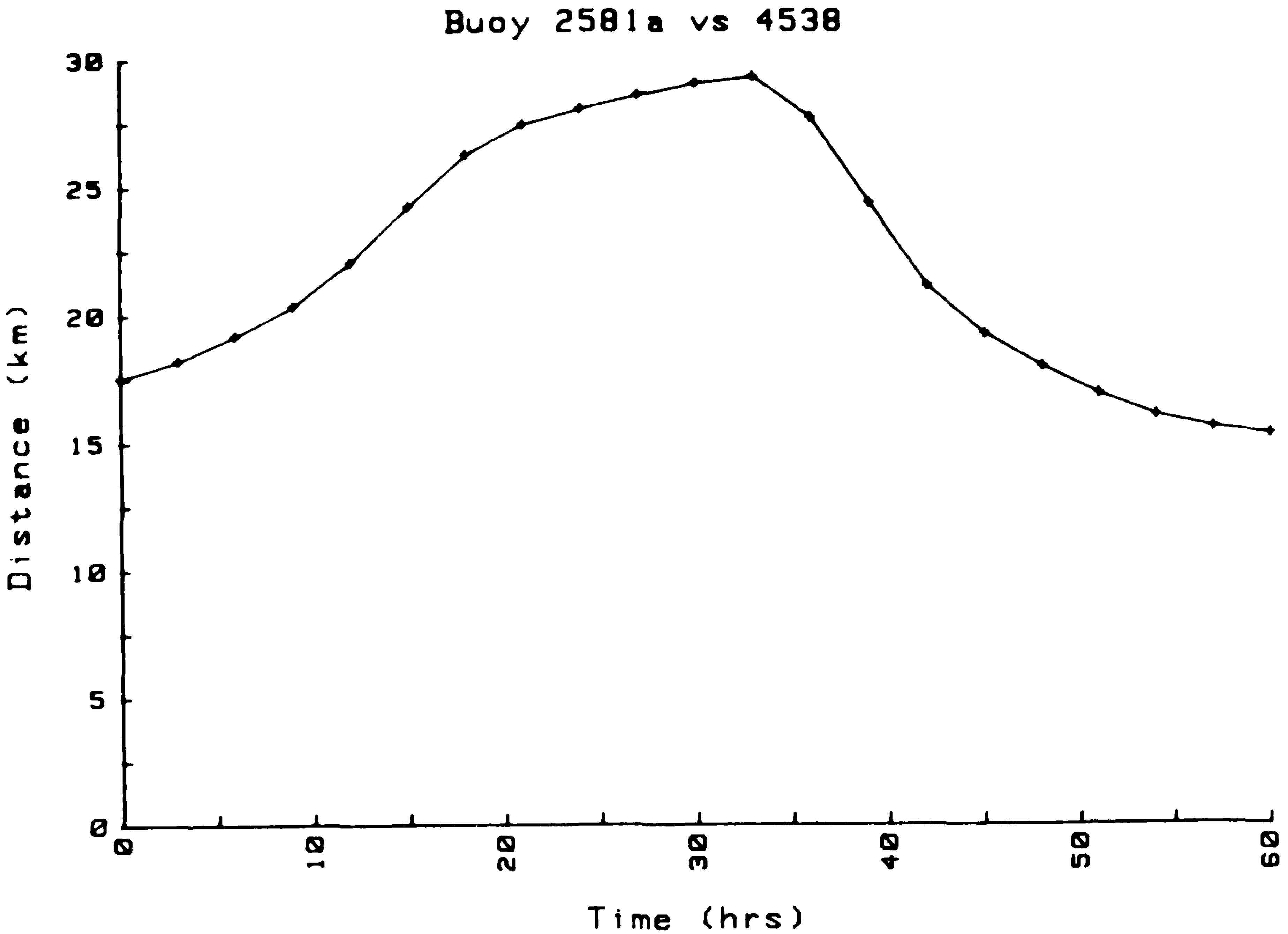


FIGURE 5-10a. SEPARATION BETWEEN BUOYS 2581a AND 4538 (1985) VERSUS TIME

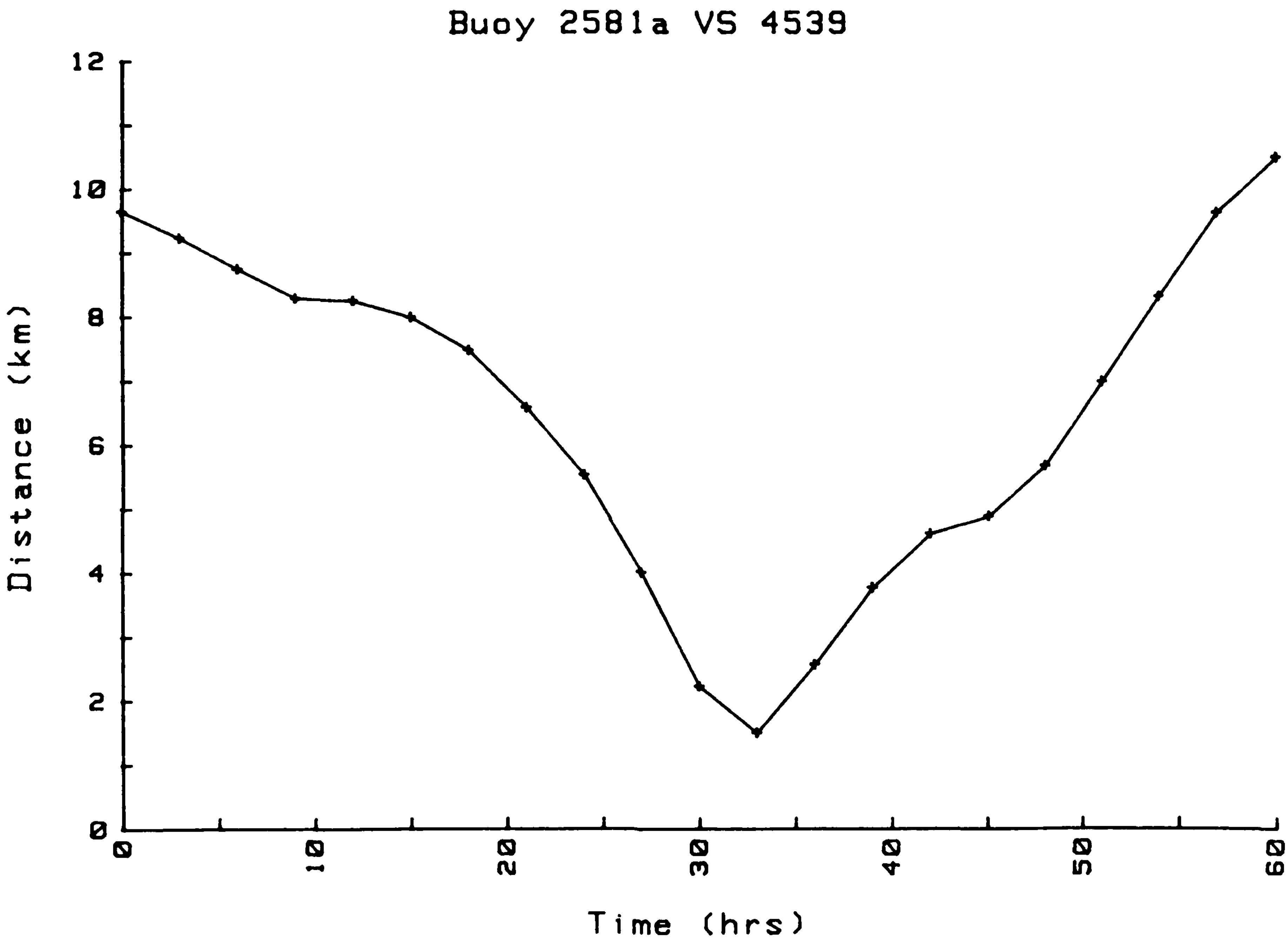


FIGURE 5-10b. SEPARATION BETWEEN BUOYS 2581a AND 4539 (1985) VERSUS TIME

this paper, one buoy (4538) appeared to have been caught amongst ice flows during the first several days of its release. Consequently, it did not move far from its deployment location. The other two buoys initially drifted to the west where buoy 2581a appeared to stop as if it had encountered an ocean surface front. Buoy 4539, having farther to travel, eventually came within 1 km of buoy 2581a at which time they both began to drift towards the southeast. Buoy 4539 traveled closer towards the barrier islands than buoy 2581a and the separation between these buoys increased with time (see Figure 5-10b). Local wind data was obtained from the Prudhoe Bay area for the period in which these buoys were drifting. This data indicated that a near 180° windshift did occur on 11 August 1985 and again on 12 August 1985 (St Martin and Lissauer, 1986). From this explanation, one can see that at least three separate factors were at work in determining the drift of these three buoys; effect of ice coverage, local wind effects, and an ocean surface front. The effect of nearshore topography also may have played a role in the variations in the movement of these buoys.

Overall, the buoy pairs that were examined for each of these [illegible] years have shown that the forcing which drove each of the [illegible] buoys was variable enough to cause great variations in the relative movement. With the effect of local winds, river [illegible] coverage, topography, and local surface currents, these buoys did not drift in similar directions and/or speeds for [illegible] periods.

6.0 CONCLUSIONS

An analysis of the trajectories of satellite buoys which were released in the southern Beaufort Sea has revealed that it may be possible to estimate surface currents if information about the large scale wind is available. Buoys, which were deployed during six years from two locations in the southern Beaufort Sea, exhibited the following general characteristics:

a. During the majority of the time, speeds were less than 30 cm/sec. Higher speeds generally occurred in an alongshore direction.

b. During the majority of the time, the buoys traveled alongshore (east/west). Excursions perpendicular to shore were generally short lived and often in conjunction with a spiral movement of the buoy.

c. Over a long term (at least 2 weeks) the u-component of the buoys' direction was the same as the direction from which the calculated geostrophic wind was blowing. Buoys speeds as a percentage of wind speed were mostly between 1 and 5%. During years of steadier winds (either easterly or westerly), the buoys were more responsive to the effects of the wind.

d. The total forcing function driving the motion of these buoys was generally variable enough to cause buoys deployed in close spacial and time proximity to drift at varying speeds and directions from each other.

e. The calculated cumulative geostrophic wind (U-direction examined only) may be useful as an estimator of generalized buoy movement. Although the speed of each buoy was generally lower than 3.5% of the wind speed, a strong coupling to the geostrophic wind was noticed. The cumulative wind is more reliable than an average wind since the average wind does not take into account tha effects of the variability in the wind.

f. The type of satellite-tracked buoys used during the later years of this experiment were extremely reliable. As has already been recommended in St. Martin (1985), the use of these buoys in tracking an oil spill in the Beaufort Sea is the best available method of tracking the long-term movement of oil.

In the event of an oil spill in the Beaufort Sea, the long term movement of the spill will be primarily controlled by the large scale wind. If a satellite-tracked buoy can be deployed near the center of the spill to provide tracking capabilities, the possibility of eventual cleanup will be enhanced. Otherwise, and in conjunction with the use of one or more of these buoys, the calculation of a cumulative geostrophic wind during the life of the spill can provide a gross estimate of the movement of the oil. As these methods do not consider the dispersion of oil, the actual area of the ocean that a spill may cover have will need to be estimated by other means.

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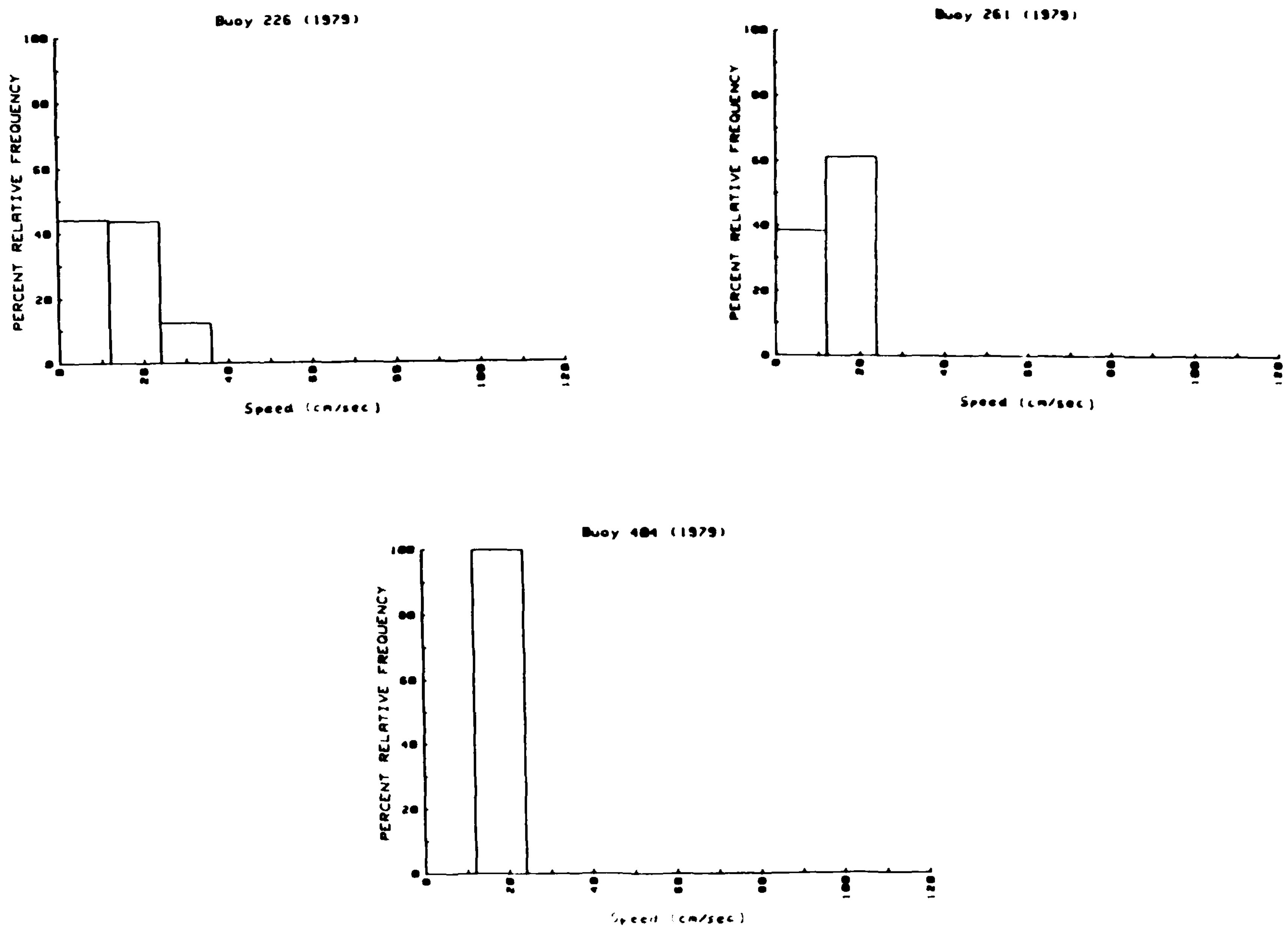
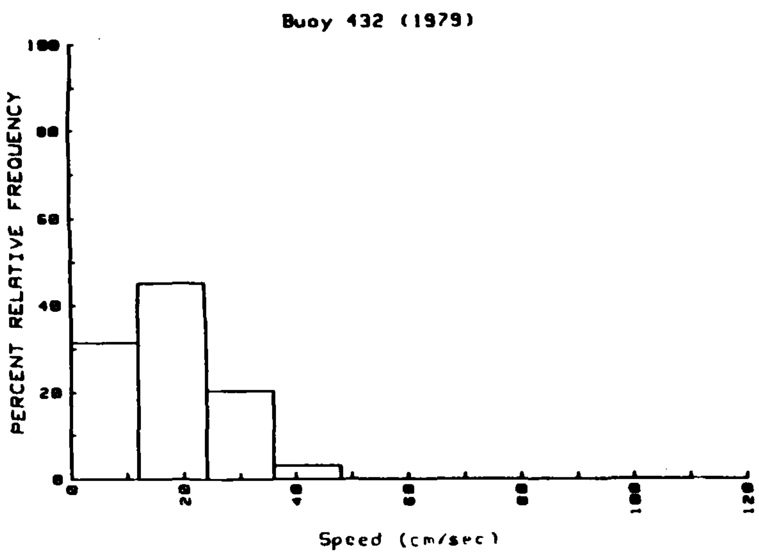
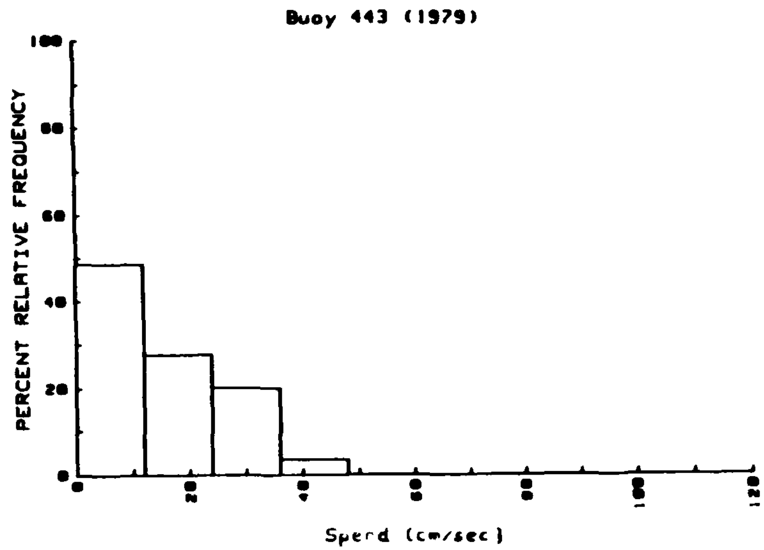
APPENDIX A

Histograms of Buoy Speed and Direction

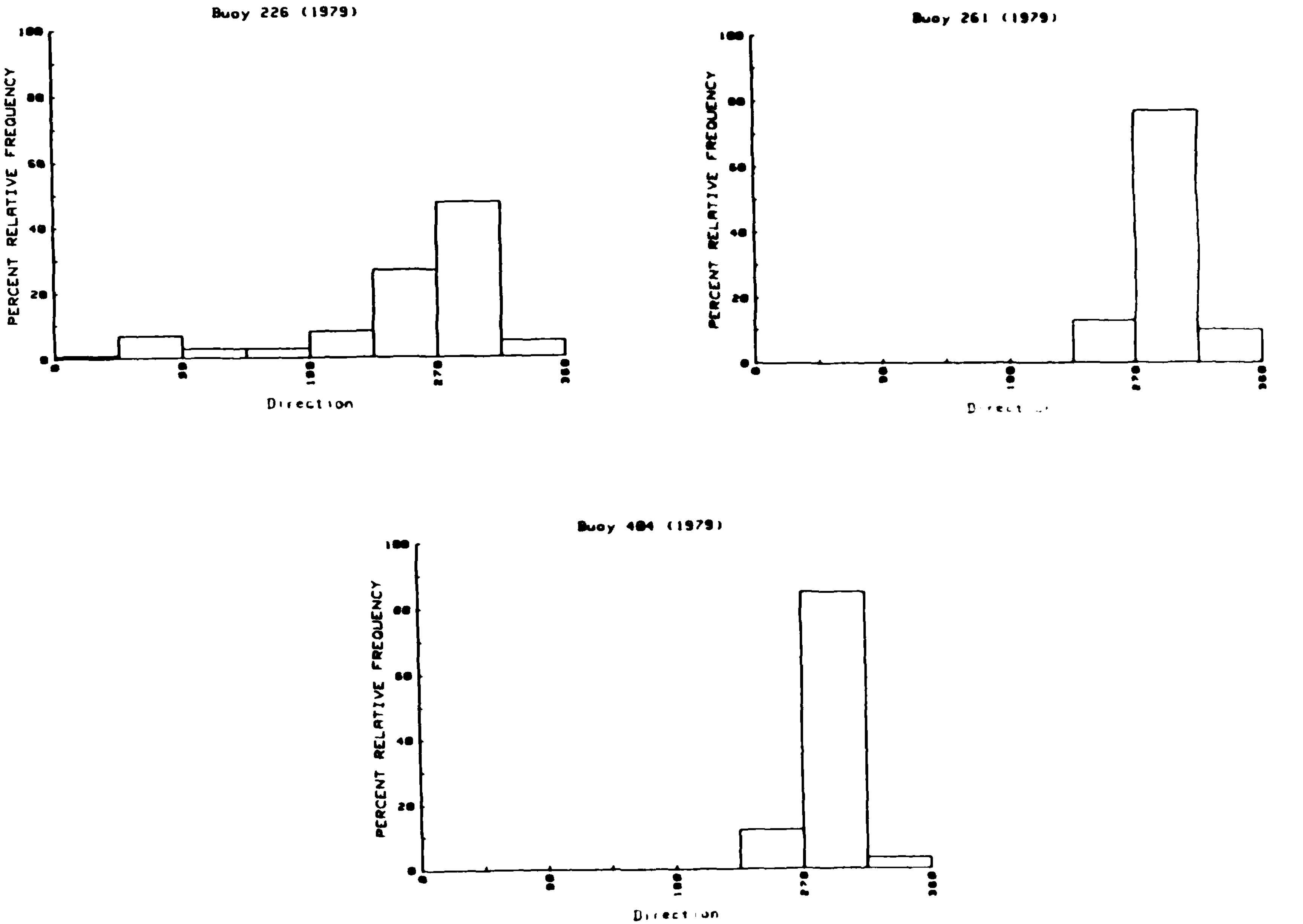


FIGURES A-1a through A-1c. HISTOGRAMS OF SPEED - BUOYS 226, 261, AND 404 (1979)

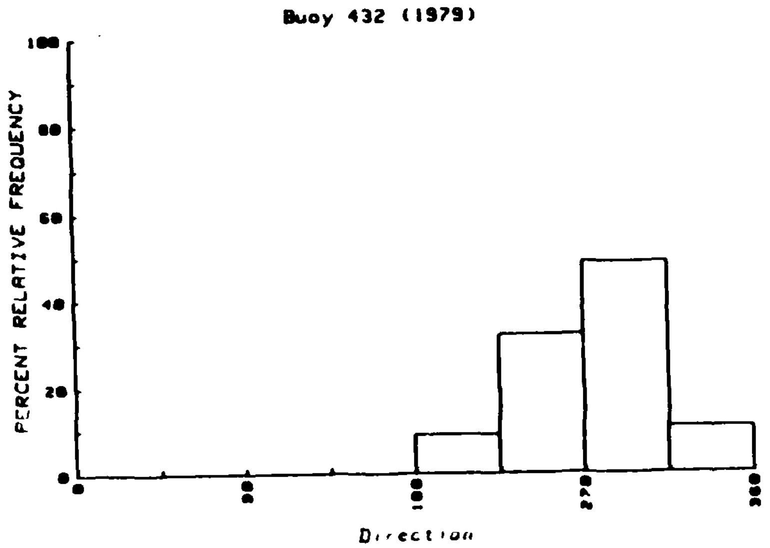


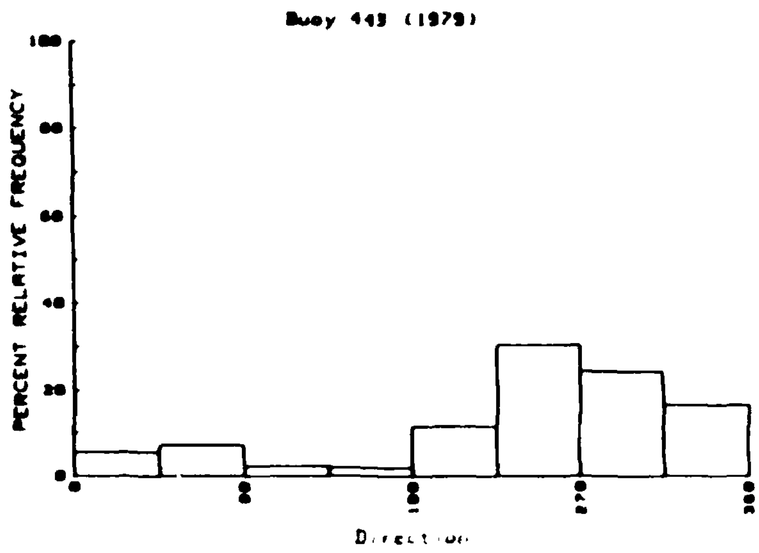


FIGURES A-1d and A-1e. HISTOGRAMS OF SPEED - BUOYS 432 AND 443 (1979)

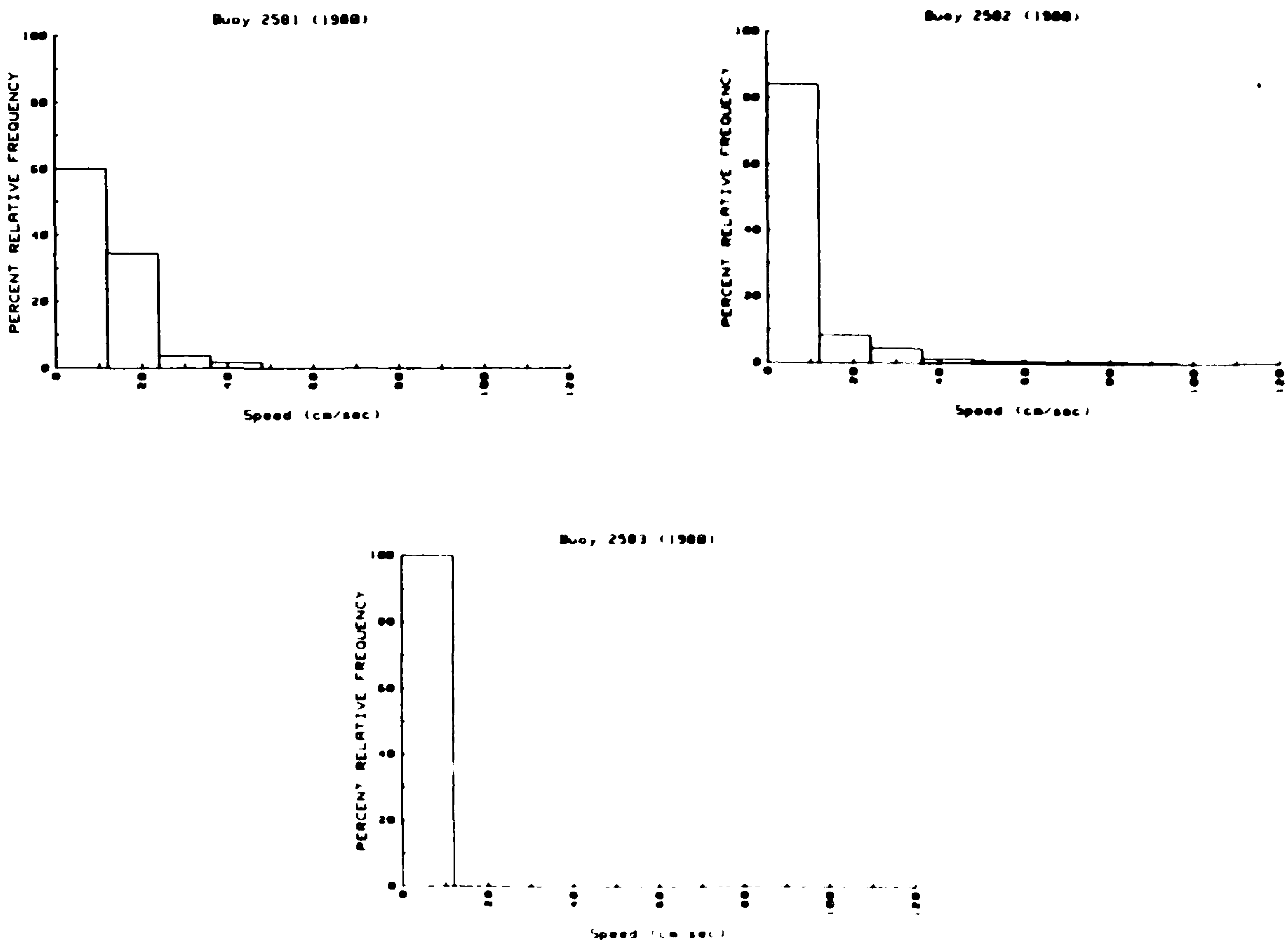


FIGURES A-2a through A-2c. HISTOGRAMS OF DIRECTION - BUOYS 226, 261, AND 404 (1979)

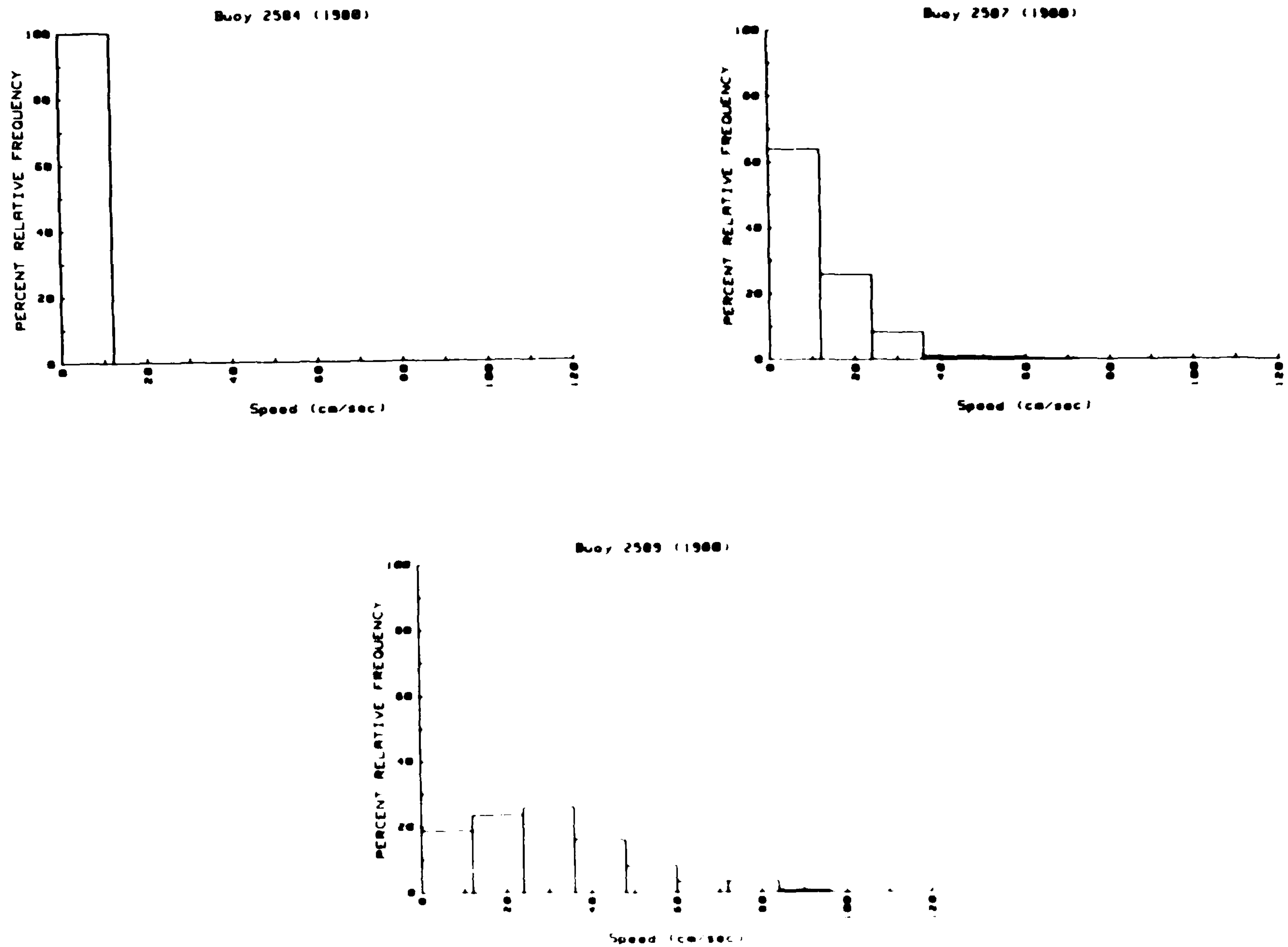




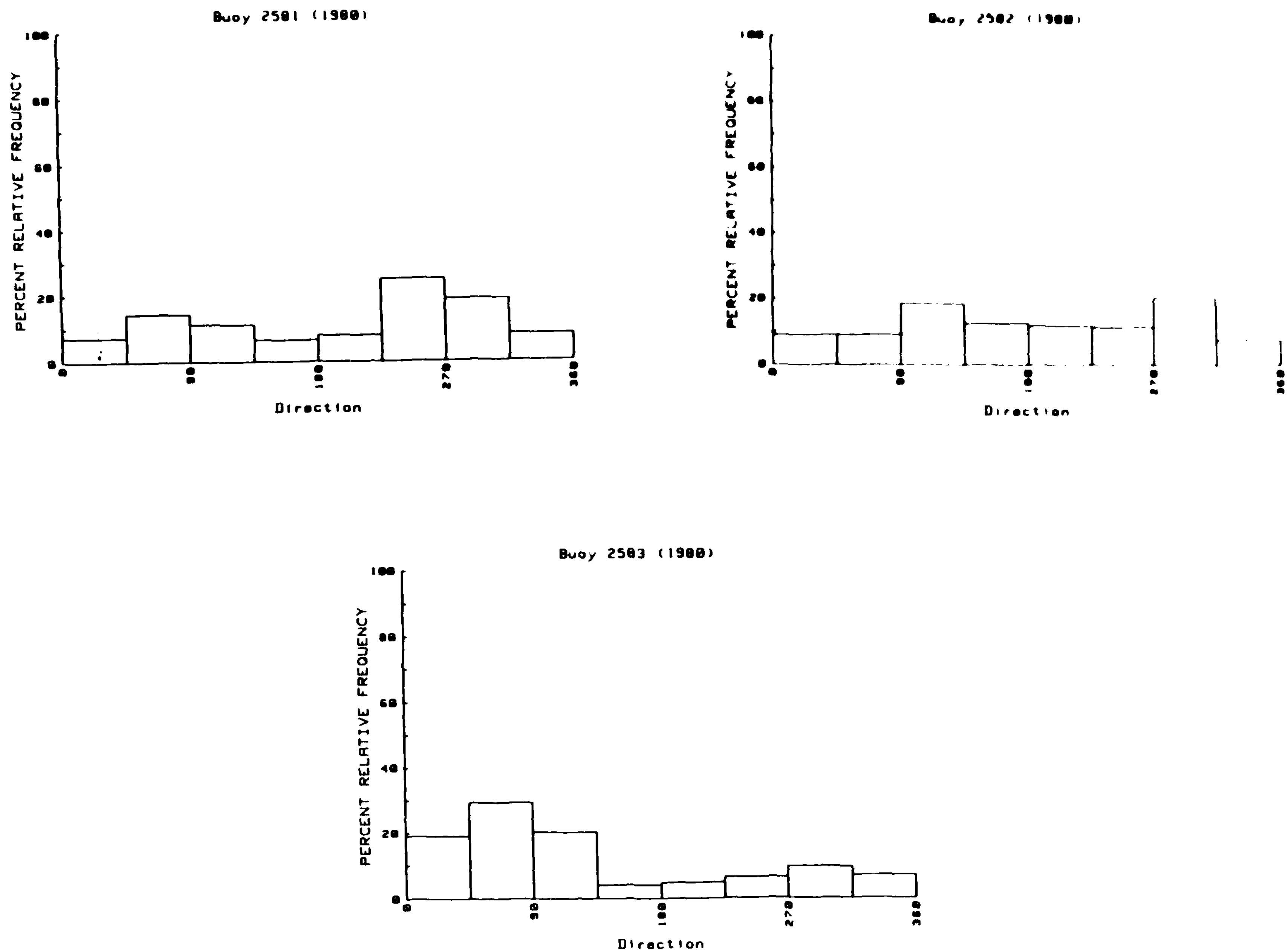
FIGURES A-2d and A-2e. HISTOGRAMS OF DIRECTION - BUOYS 432 AND 443 (1979)



FIGURES A-3a through A-3c. HISTOGRAMS OF SPEED - BUOYS 2581, 2582, AND 2583 (1980)

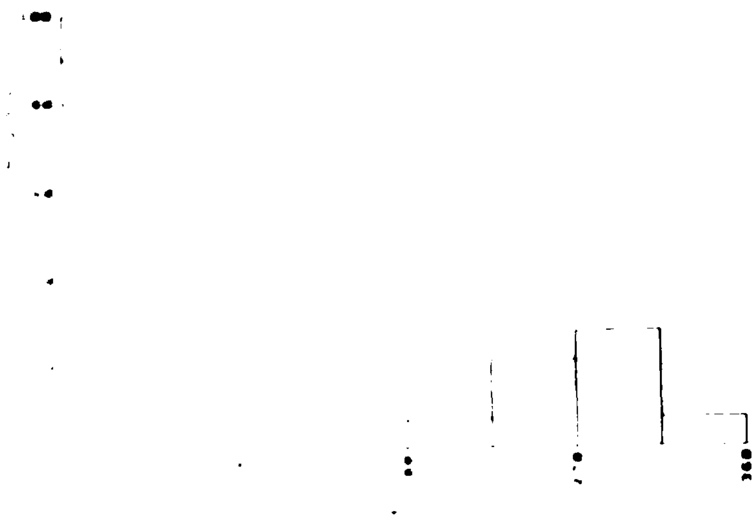


FIGURES A-3d through A-3f. HISTOGRAMS OF SPEED - BUOYS 2584, 2585, AND 2586 (1980)

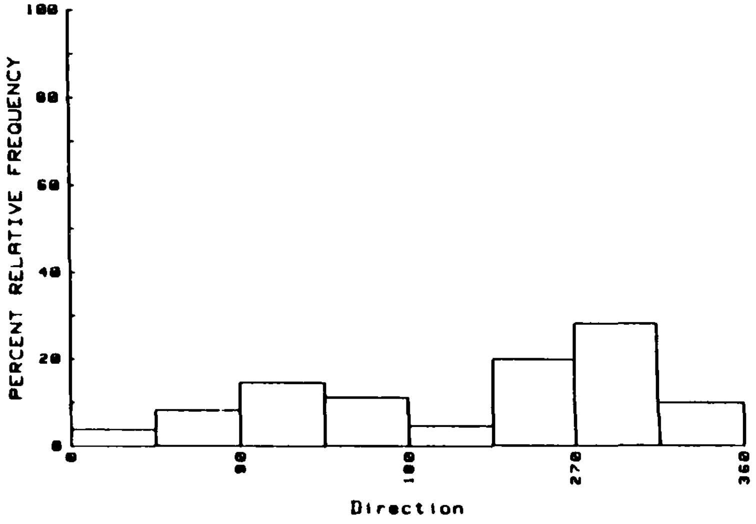


FIGURES A-4a through A-4c. HISTOGRAMS OF DIRECTION - BUOYS 2581, 2582, AND 2583 (1980)

Buoy 2584 (1980)



Buoy 2587 (1980)



[illegible] 2584, 2587 AND 2589 (1980)

AD-A182 967 ARCTIC DRIFTING BUOY DATA 1979 - 1985(U) COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CT J W ST. MARTIN APR 87 CGR/DC-07/87 USCG-D-10-87 2/2

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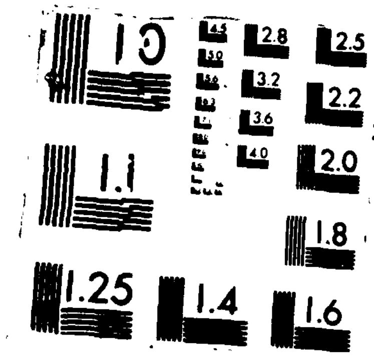
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
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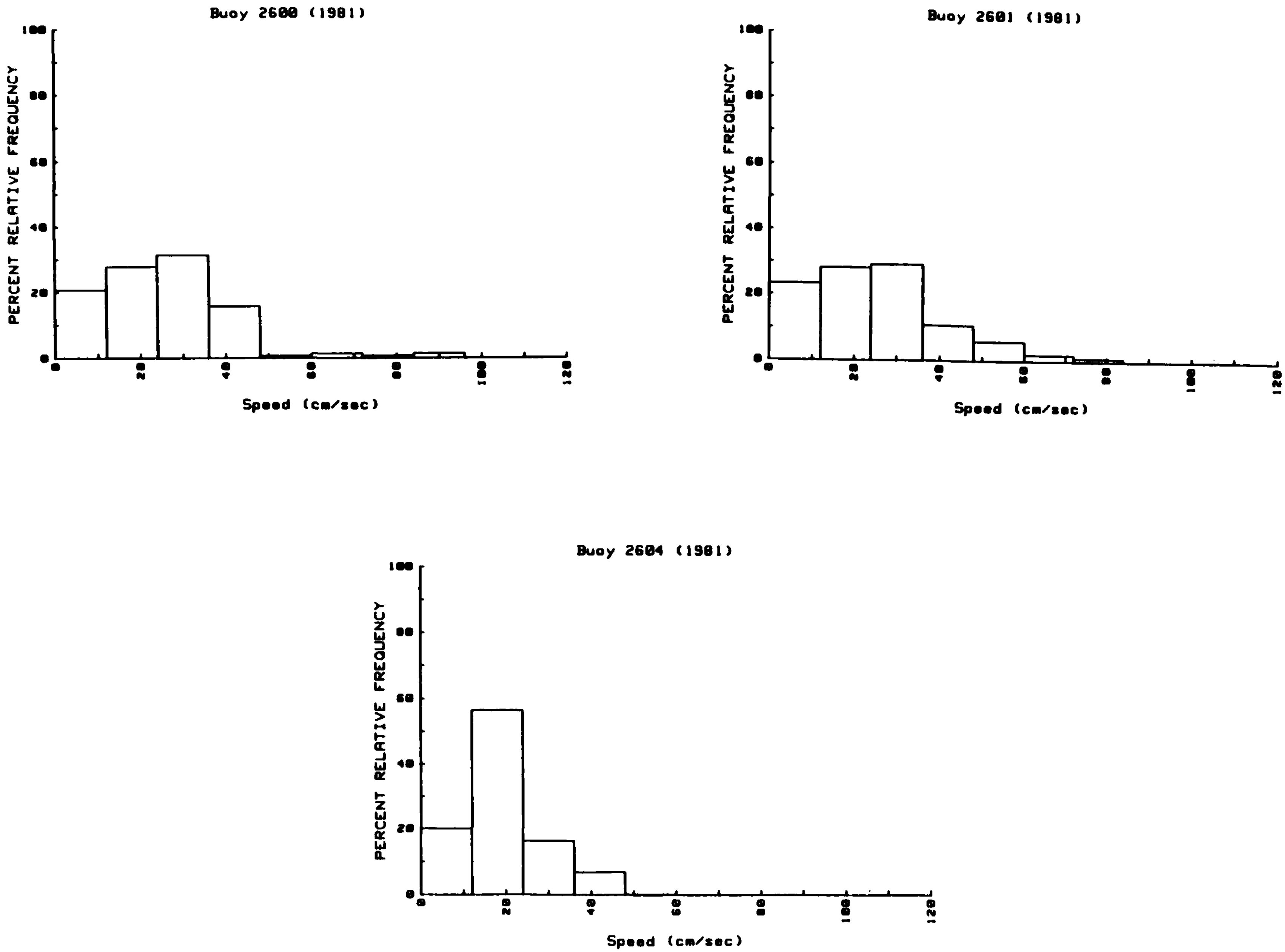
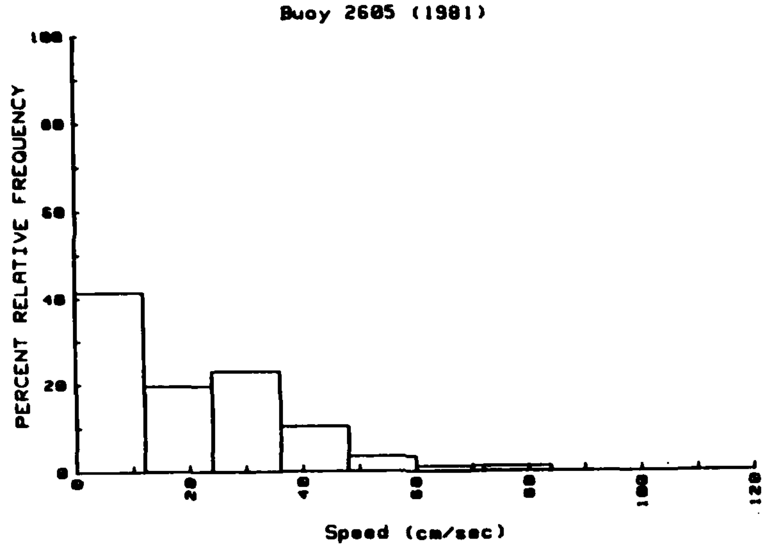
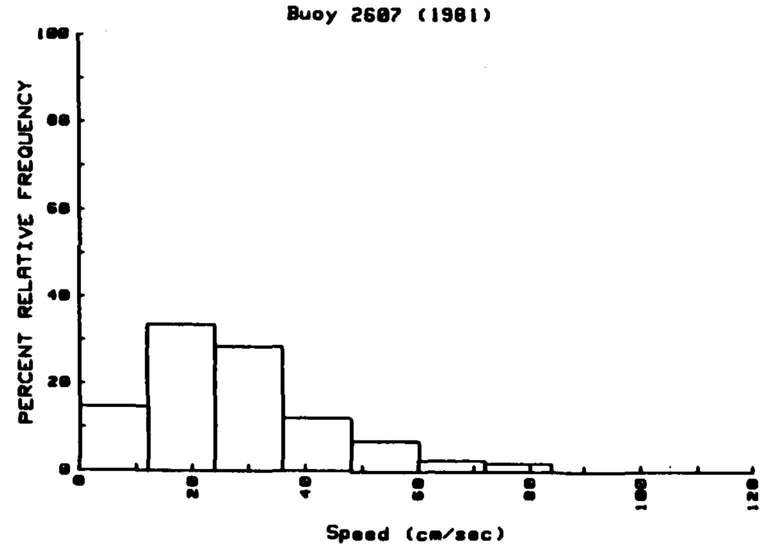
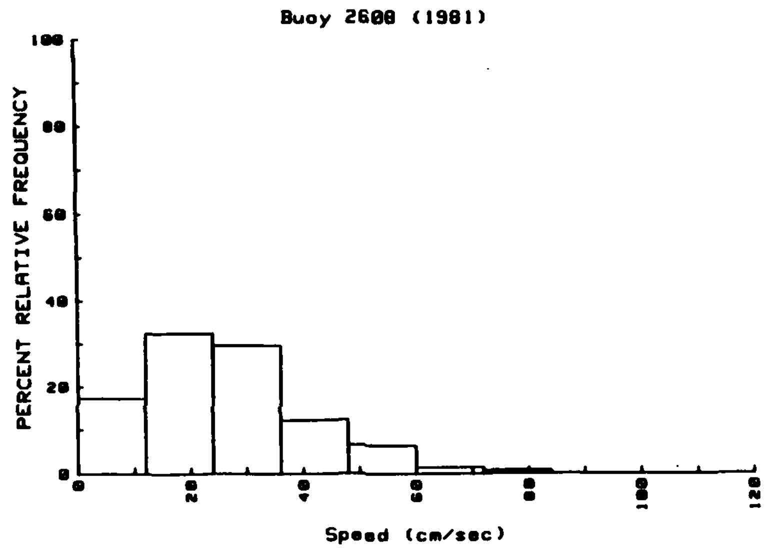
4.0



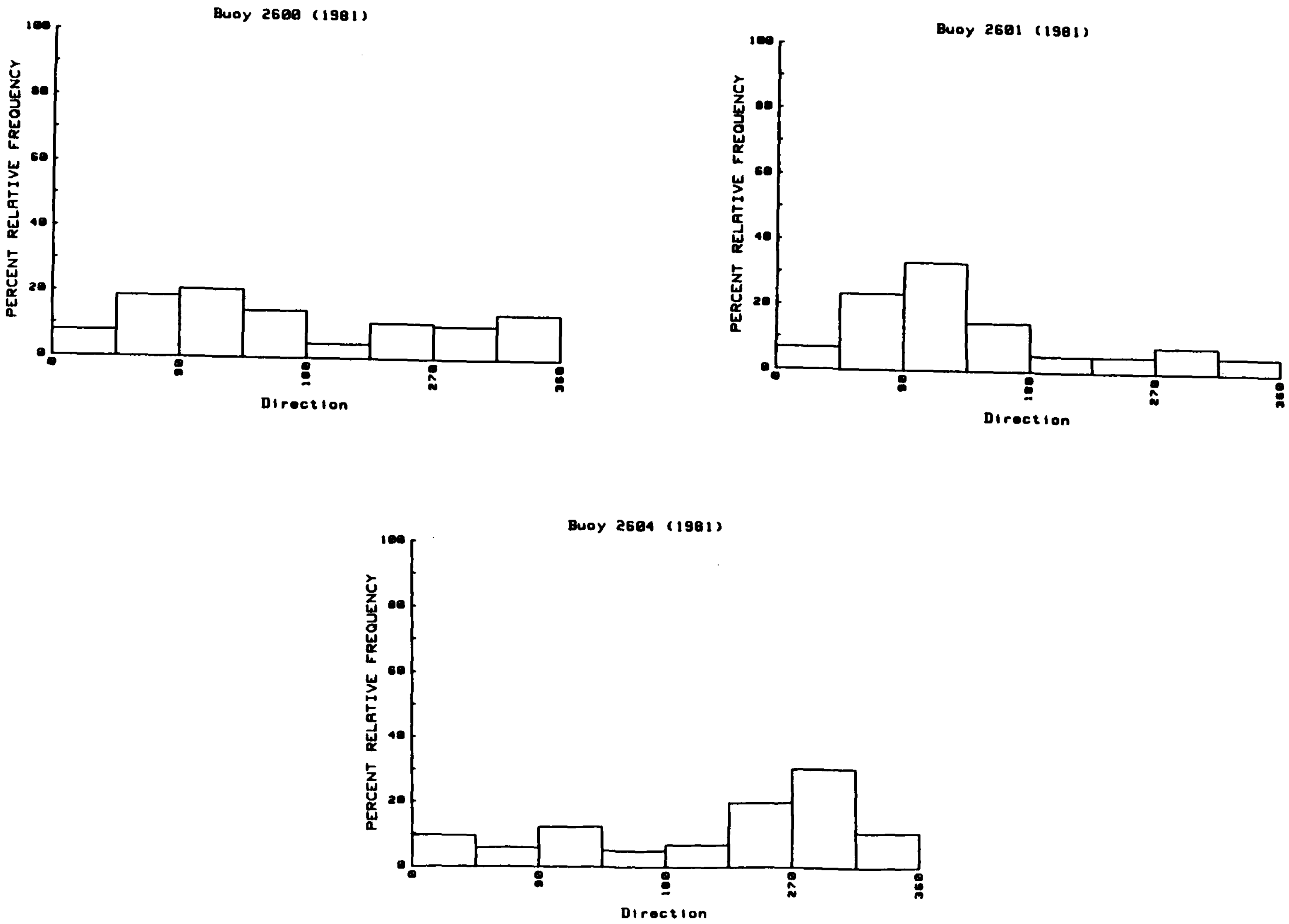
FIGURES A-5a through A-5c. HISTOGRAMS OF SPEED - BUOYS 2600, 2601, AND 2604 (1981)



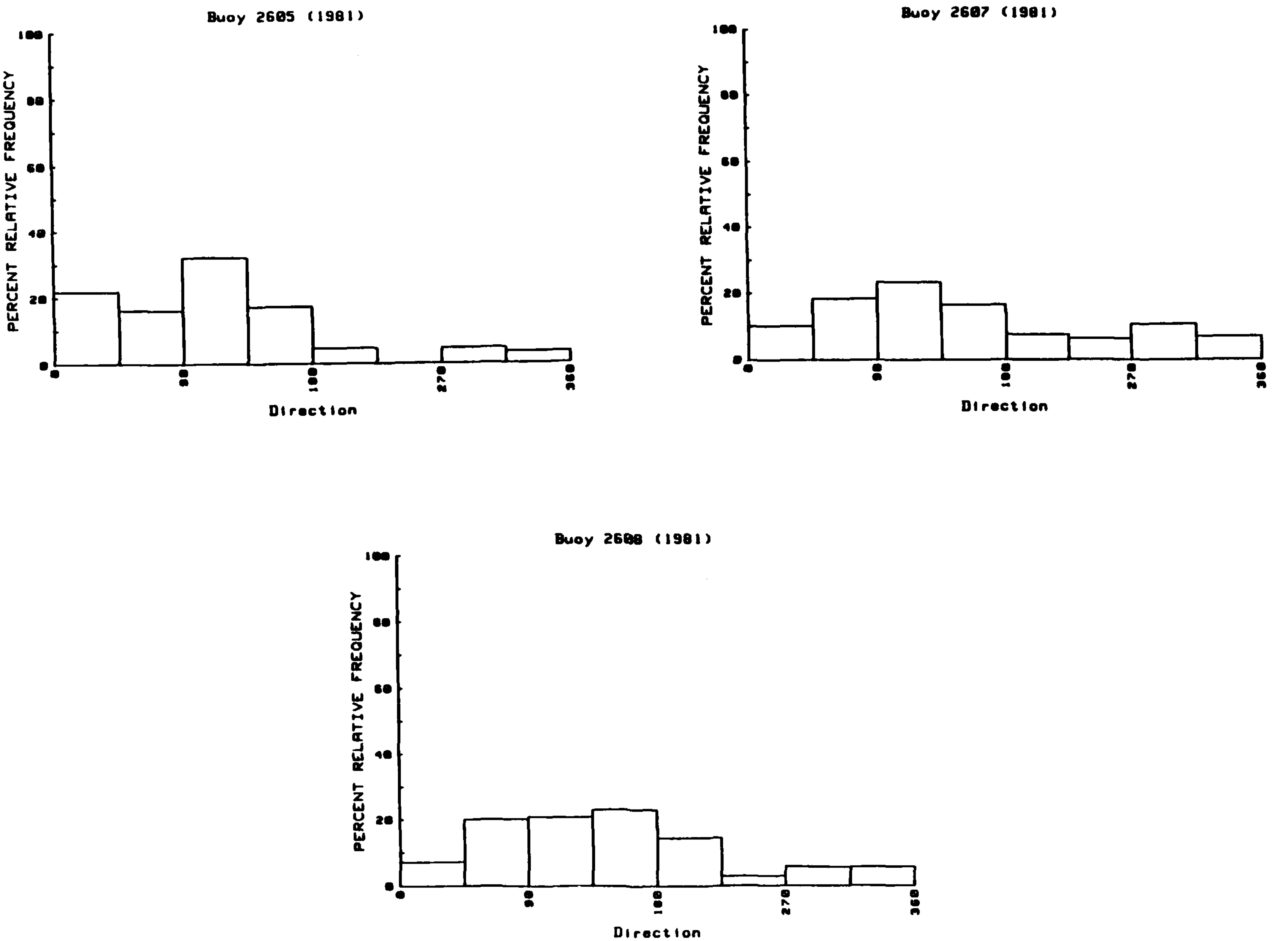




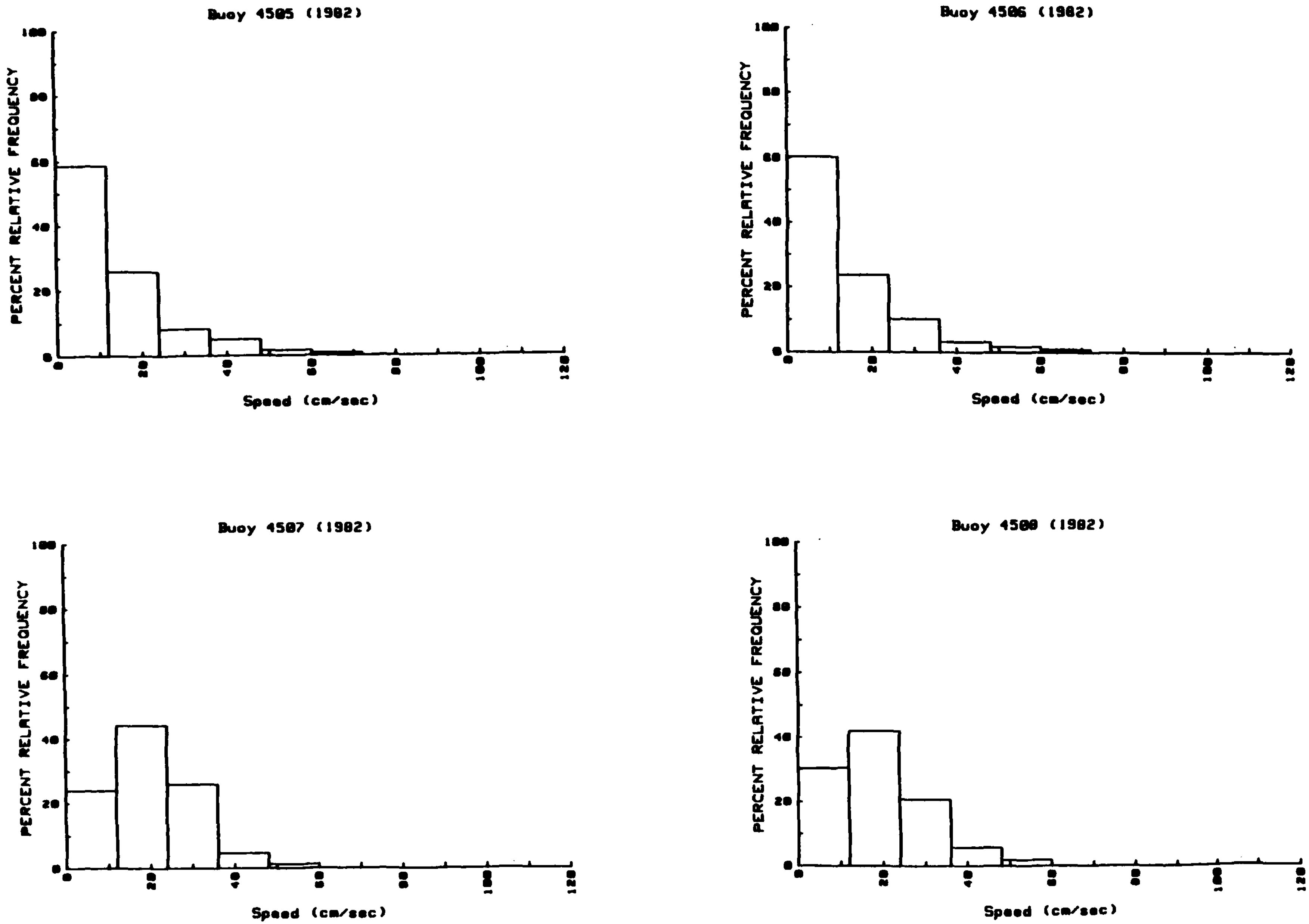
FIGURES A-5d through A-5f. HISTOGRAMS OF SPEED - BUOYS 2605, 2607, AND 2608 (1981)



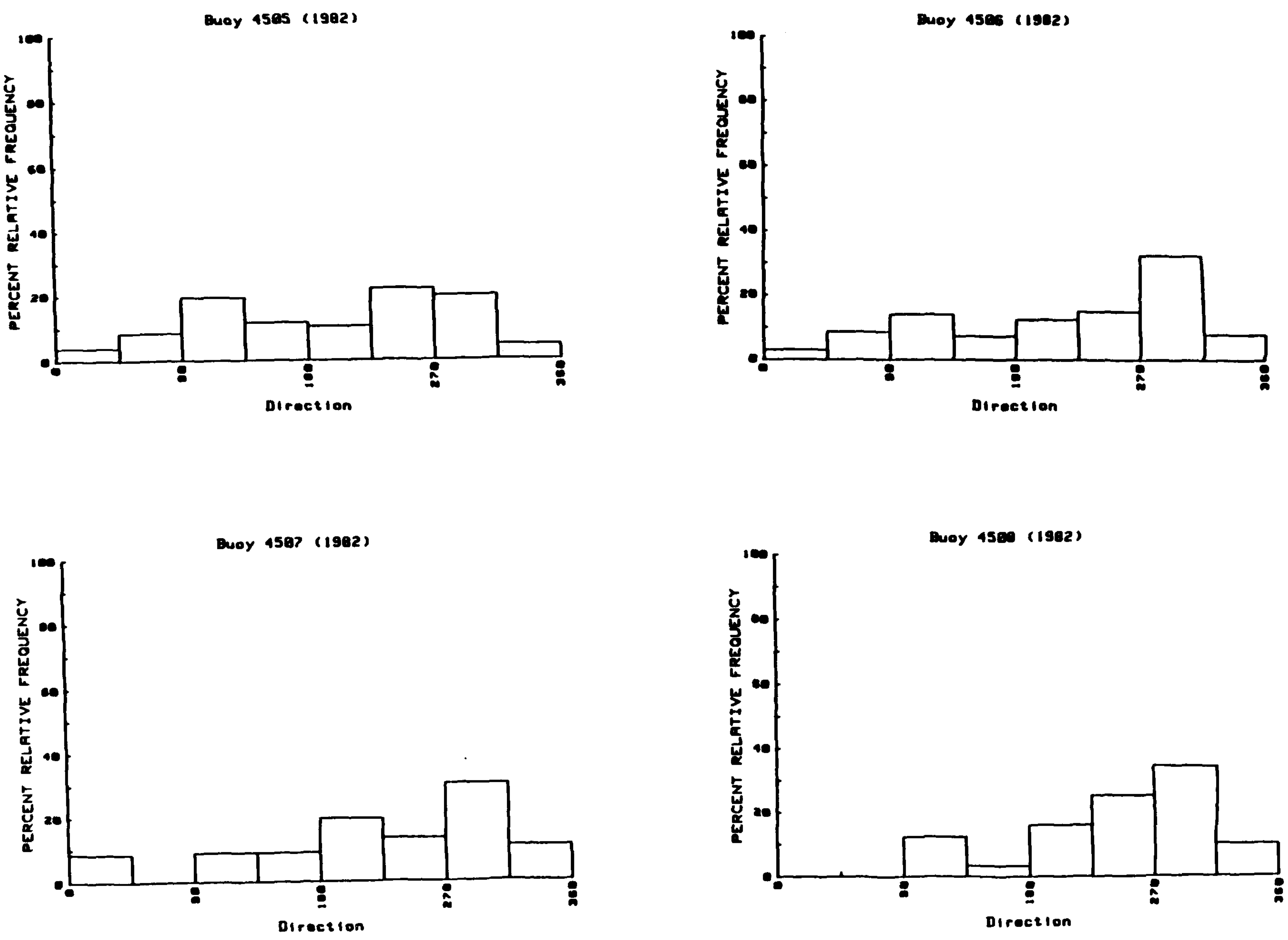
FIGURES A-6a through A-6c. HISTOGRAMS OF DIRECTION - BUOYS 2600, 2601, AND 2604 (1981)



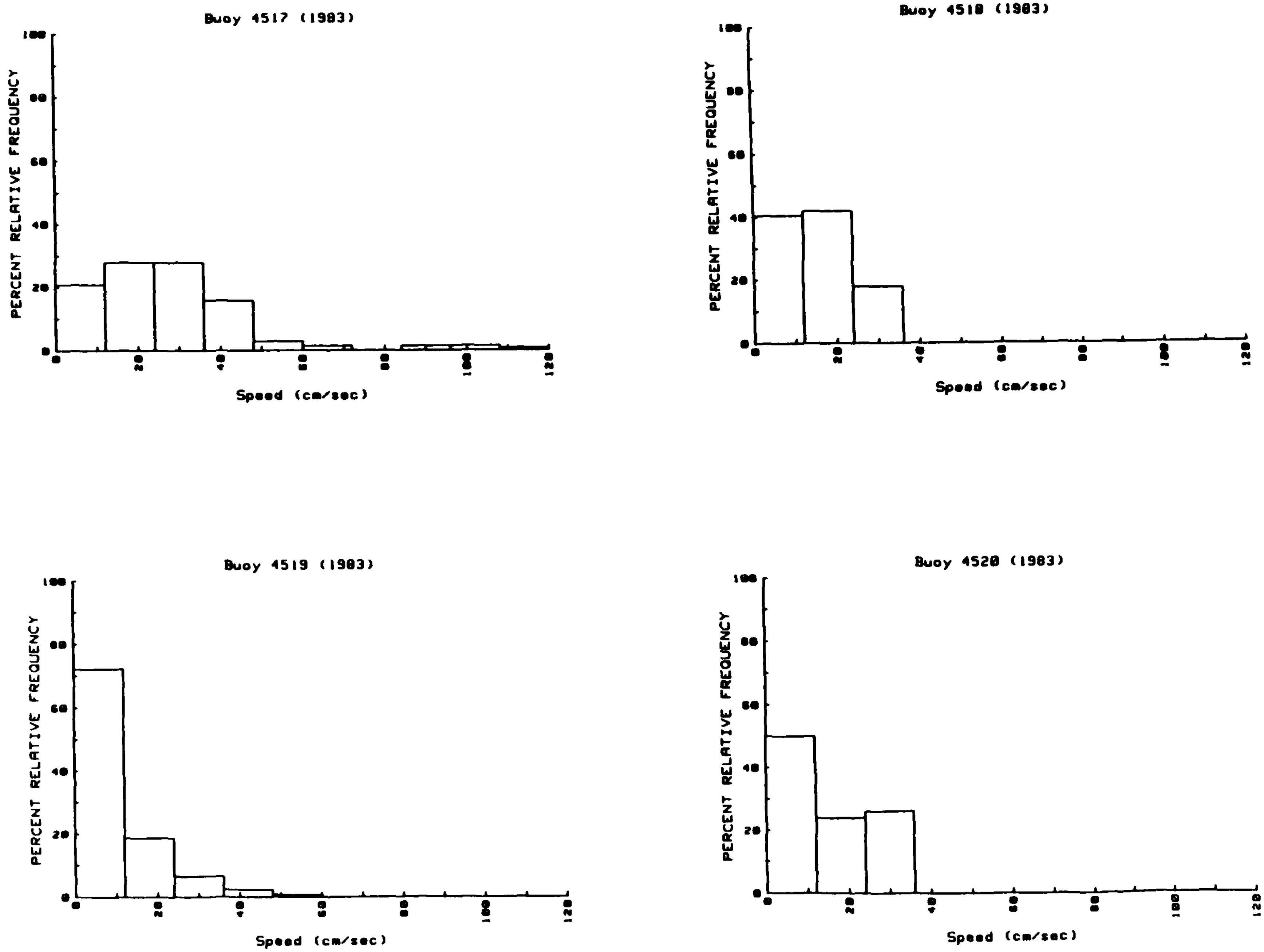
FIGURES A-6d through A-6f. HISTOGRAMS OF DIRECTION - BUOYS 2605, 2607, AND 2608 (1981)



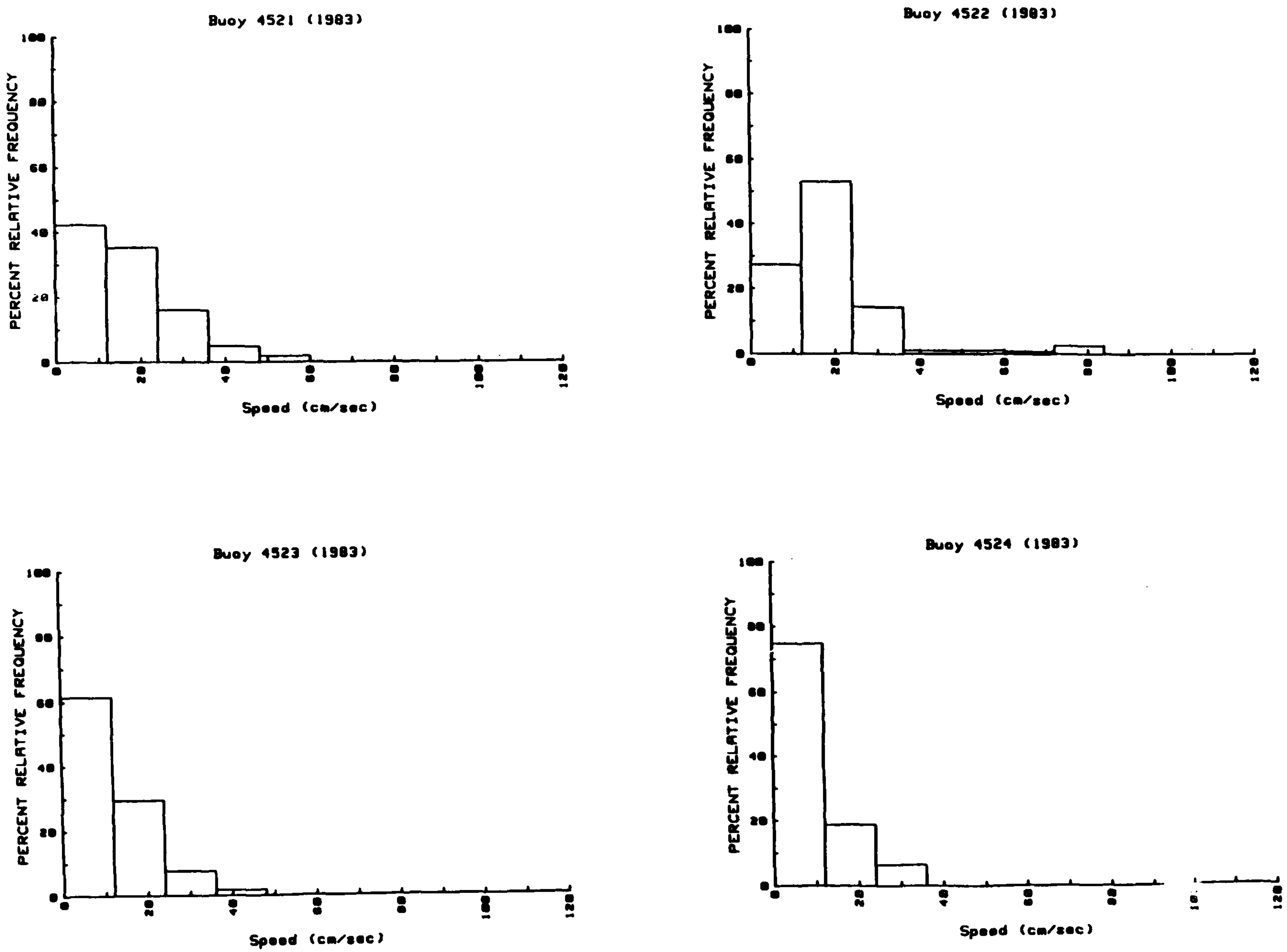
FIGURES A-7a through A-7d. HISTOGRAMS OF SPEED - BUOYS 4505, 4506, 4507, AND 4508 (1982)



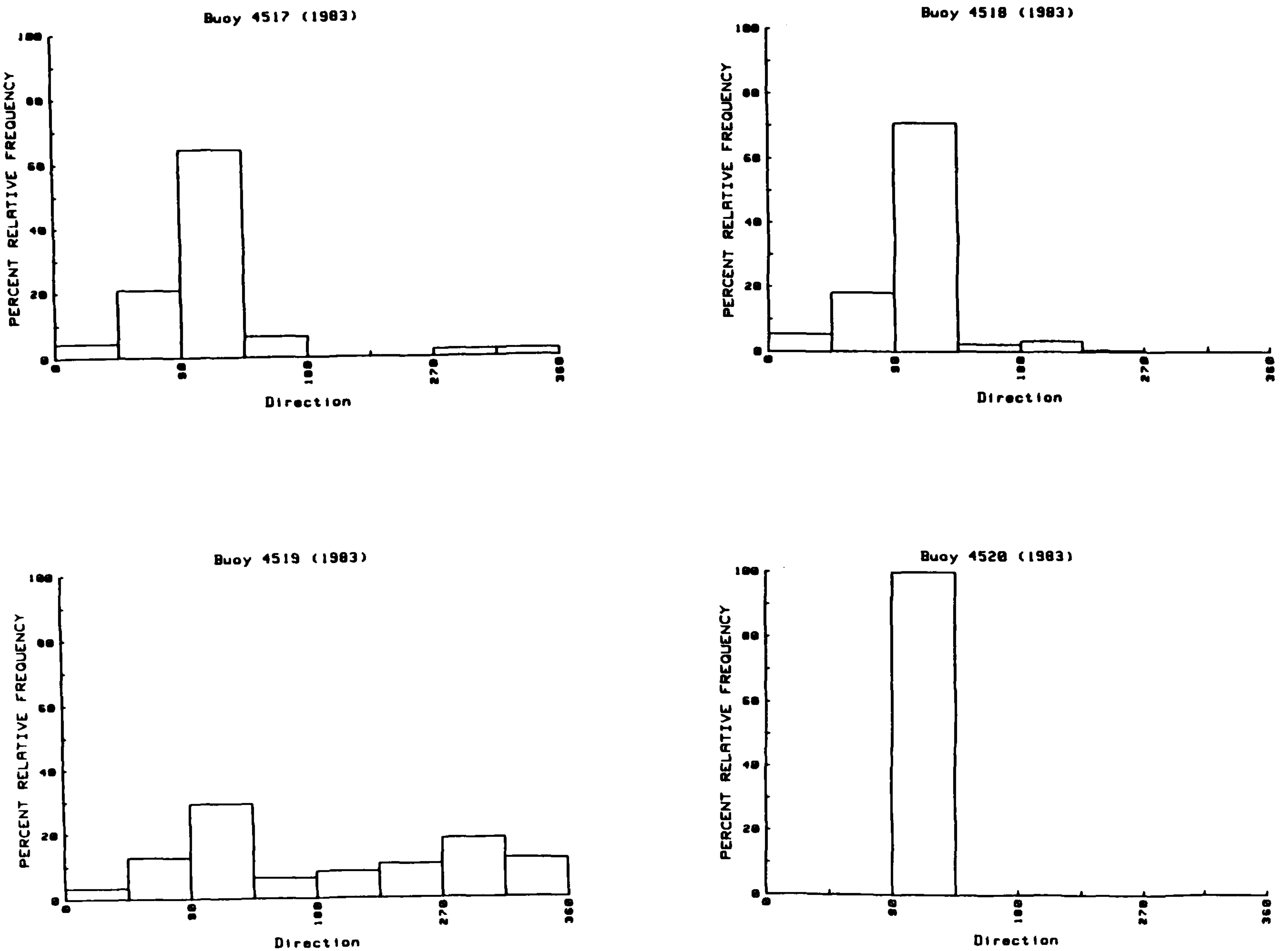
FIGURES A-8a through A-8d. HISTOGRAMS OF DIRECTION - BUOYS 4505, 4506, 4507, AND 4508 (1982)



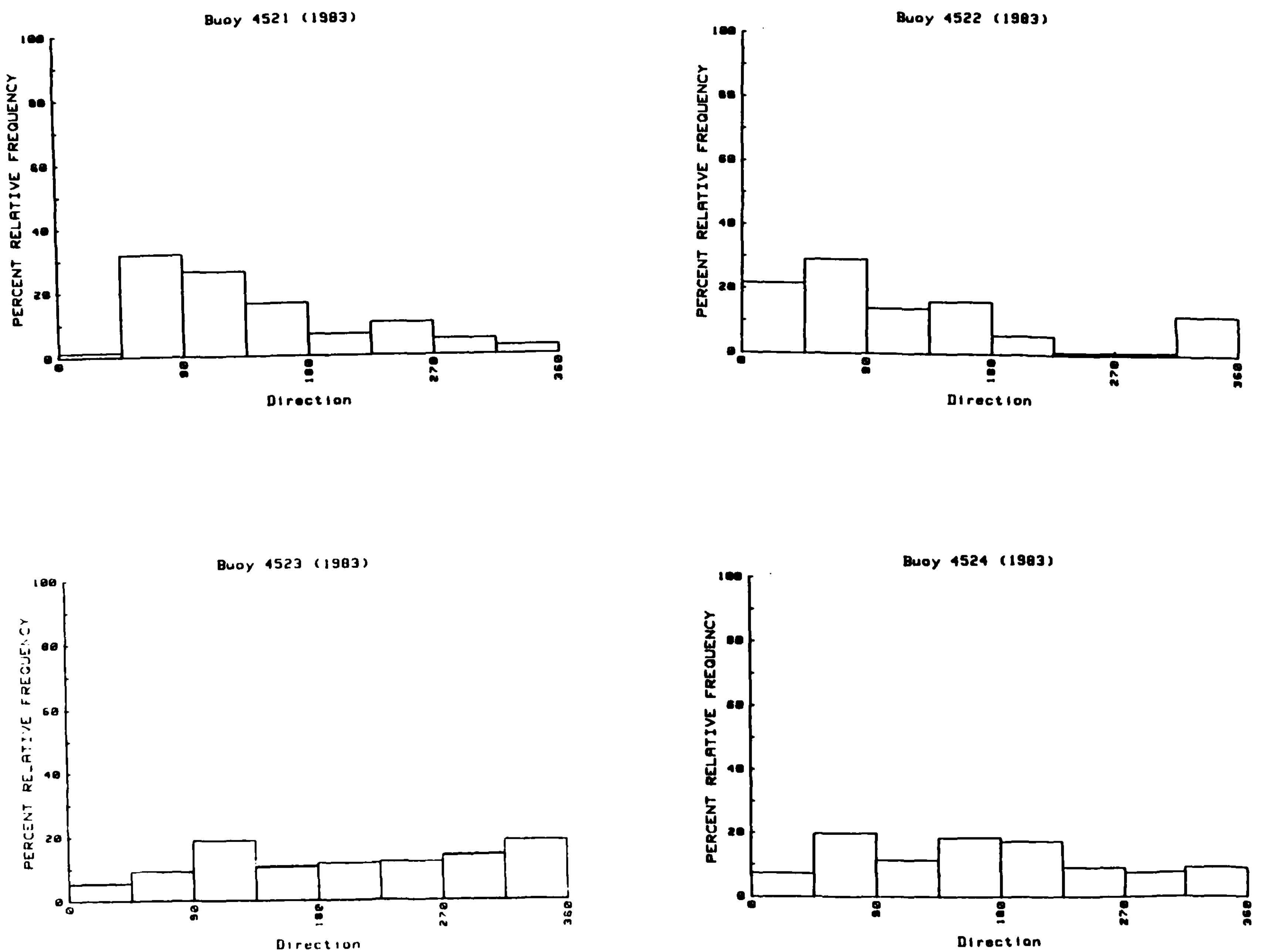
FIGURES A-9a through A-9d. HISTOGRAMS OF SPEED - BUOYS 4517, 4518, 4519 AND 4520 (1983)



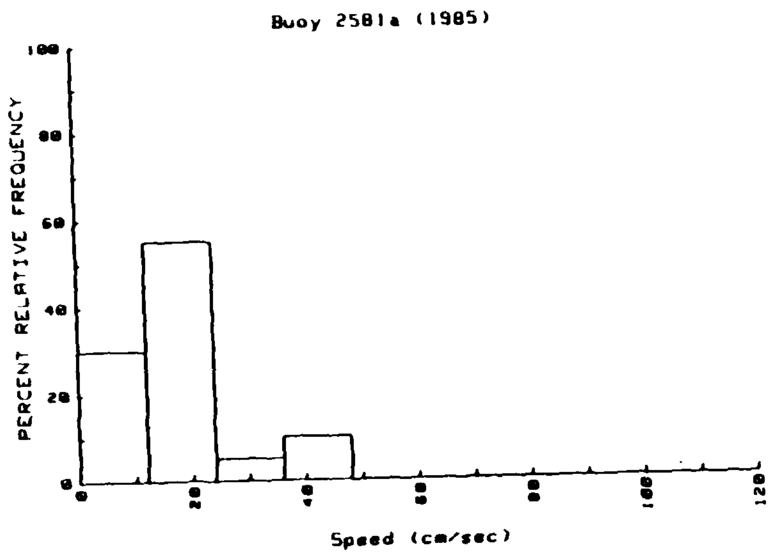
FIGURES A-9e through A-9h. HISTOGRAMS OF SPEED - BUOYS 4521, 4522, 4523, AND 4524 (1983)

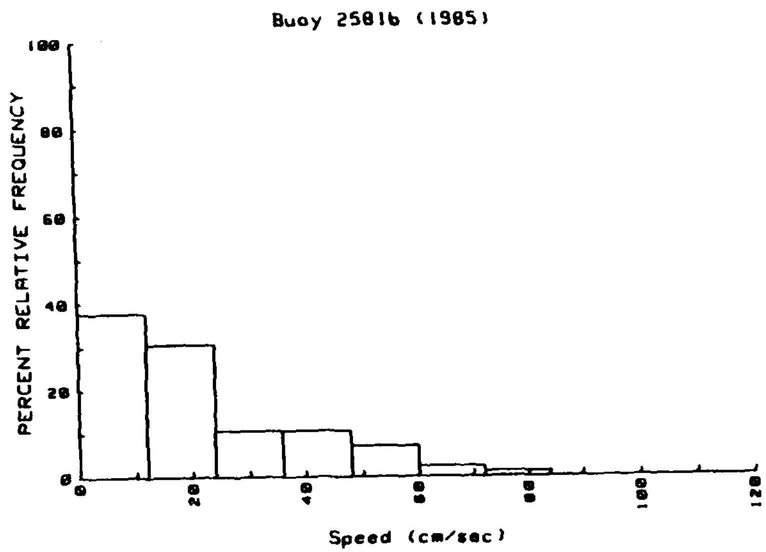


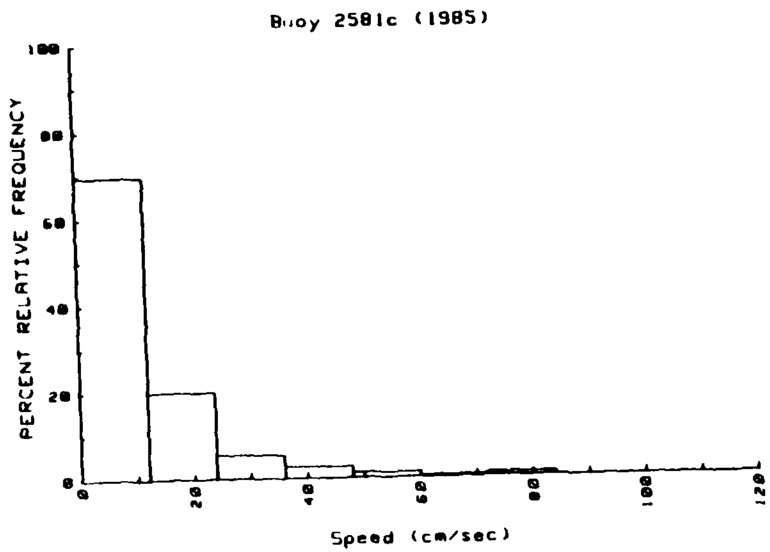
FIGURES A-10a through A-10d. HISTOGRAMS OF DIRECTION - BUOYS 4517, 4518, 4519, 4520 (1983)



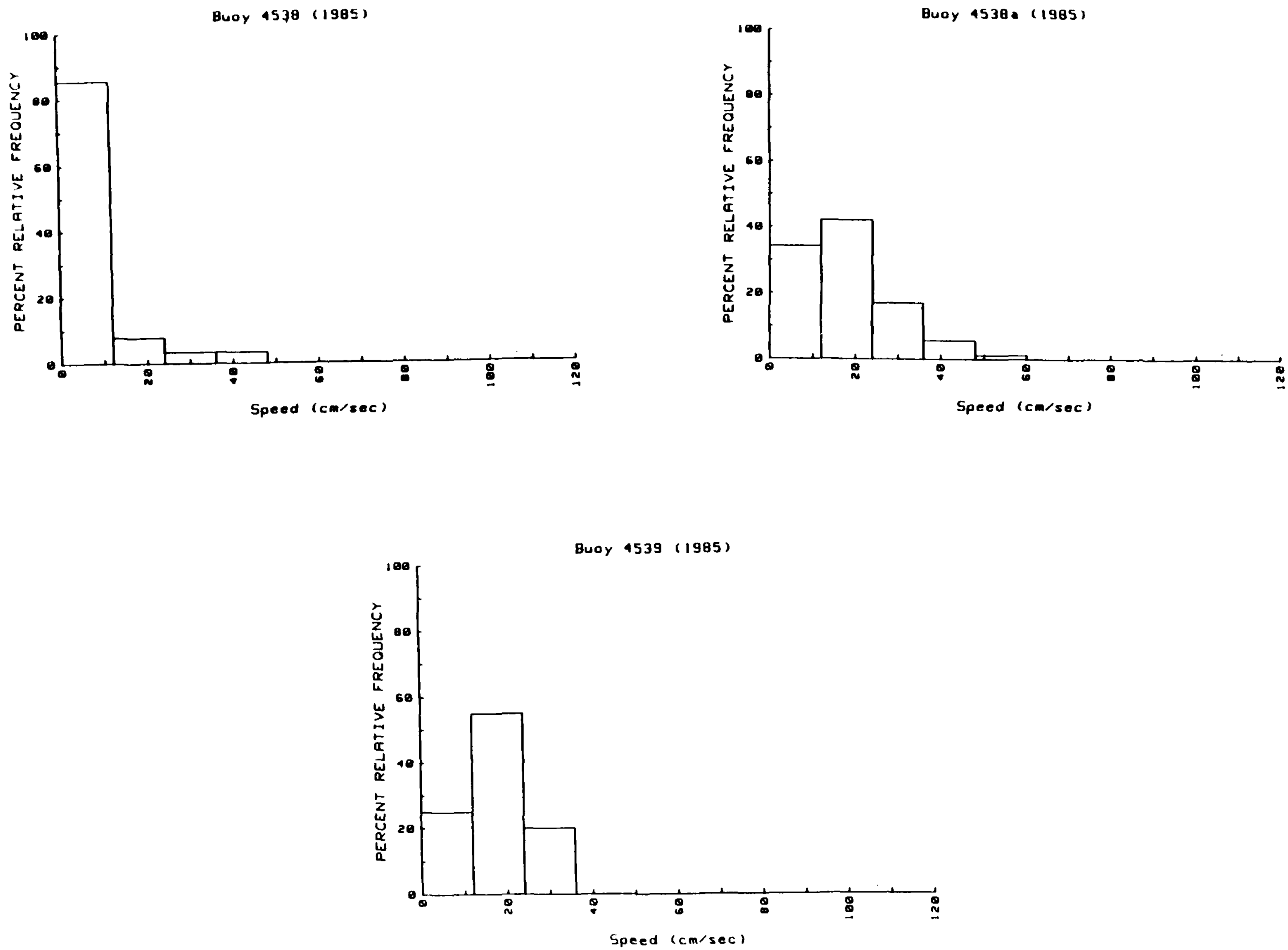
FIGURES A-10e through A-10h. HISTOGRAMS OF DIRECTION - BUOYS 4521, 4522, 4523 AND 4524 (1983)



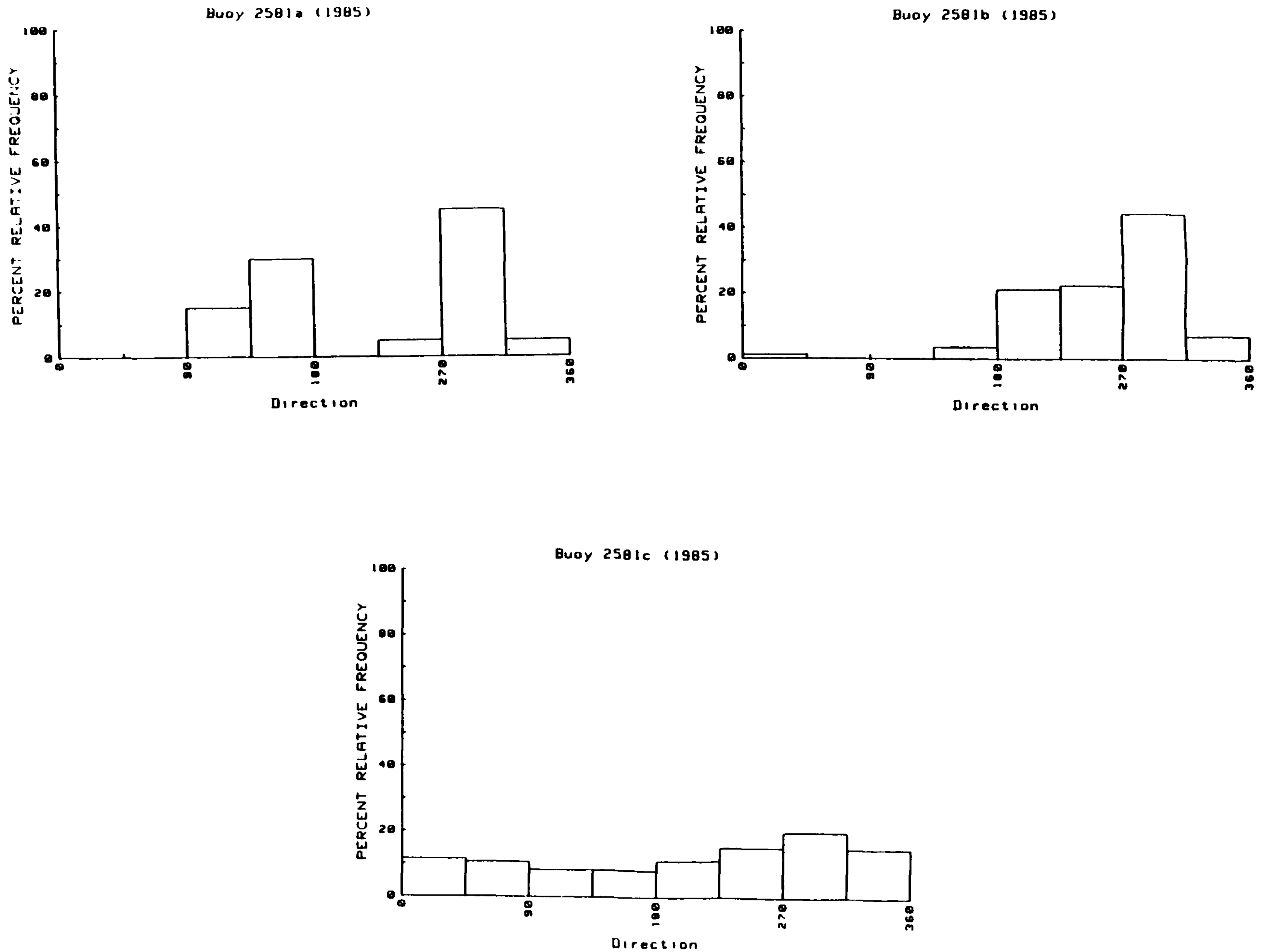




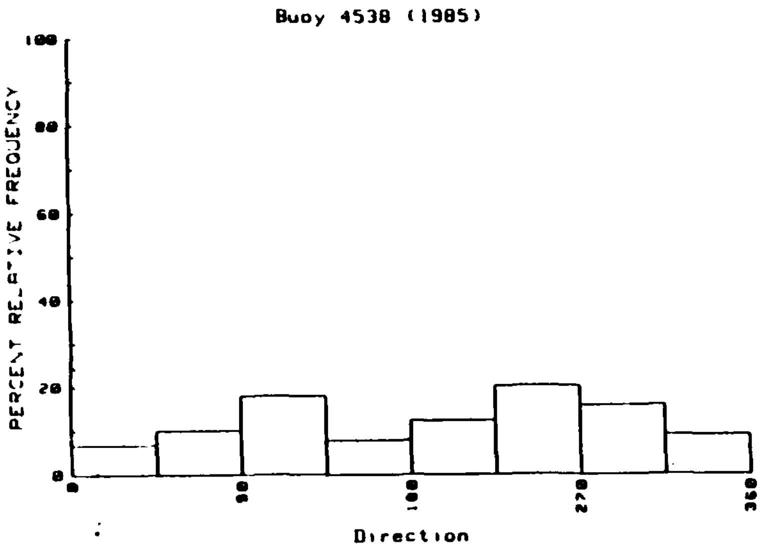
FIGURES A-11a through A-11c. HISTOGRAMS OF SPEED - BUOYS 2581a, 2581b, AND 2581c (1985)

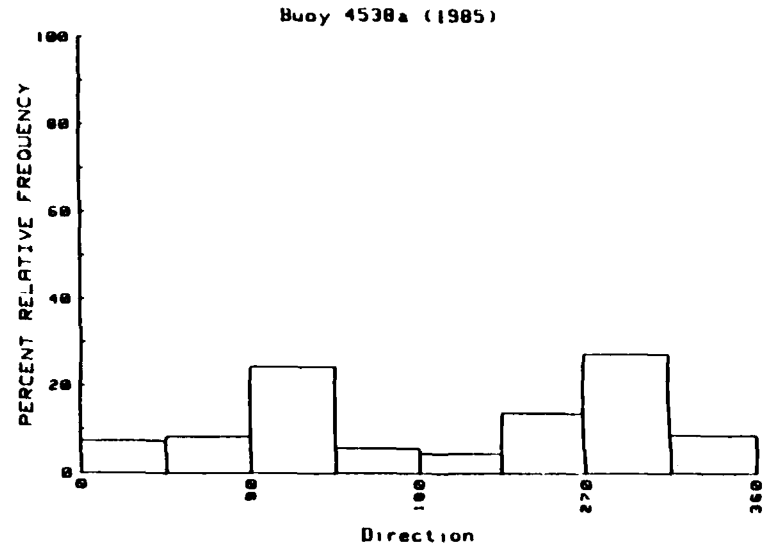


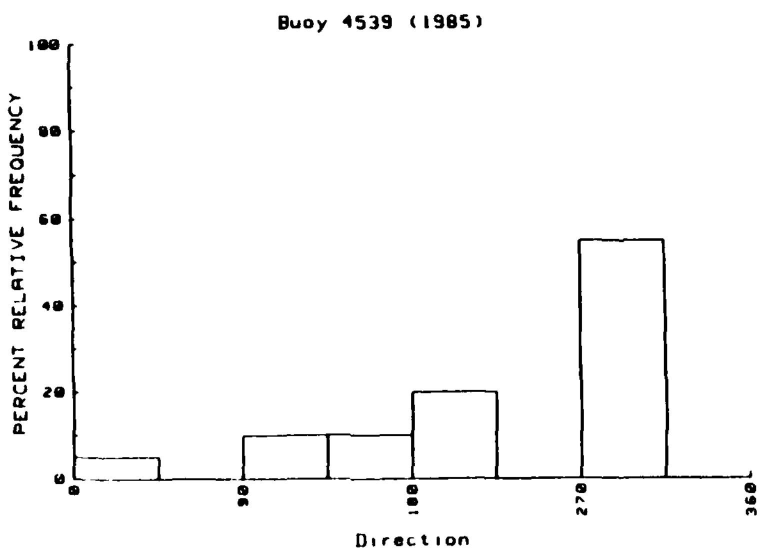
FIGURES A-11d through A-11f. HISTOGRAMS OF SPEED - BUOYS 4538, 4538a, AND 4539 (1985)



FIGURES A-12a through A-12c. HISTOGRAMS OF DIRECTION - BUOYS 2581a, 2581b, AND 2581C (1985)



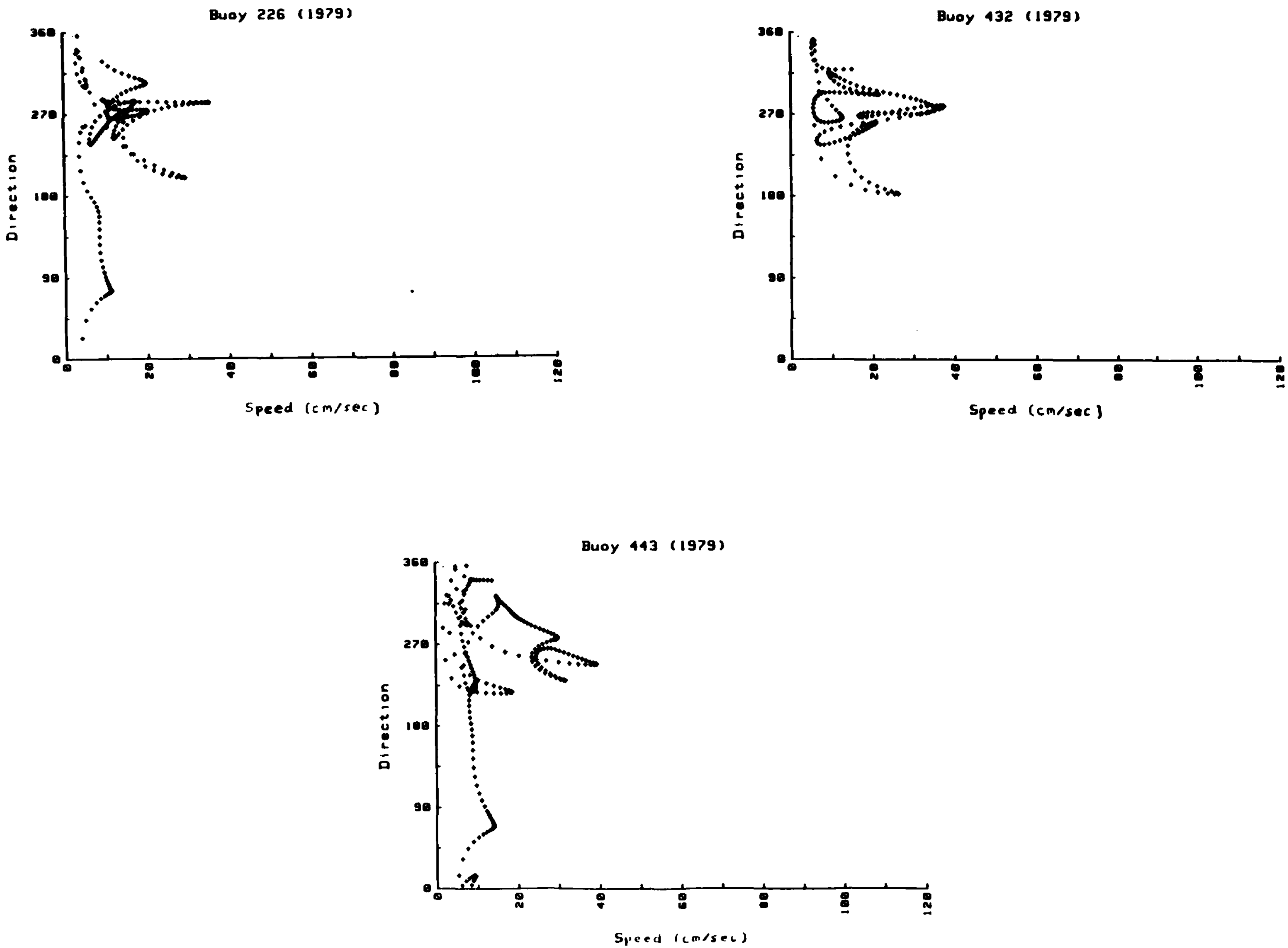




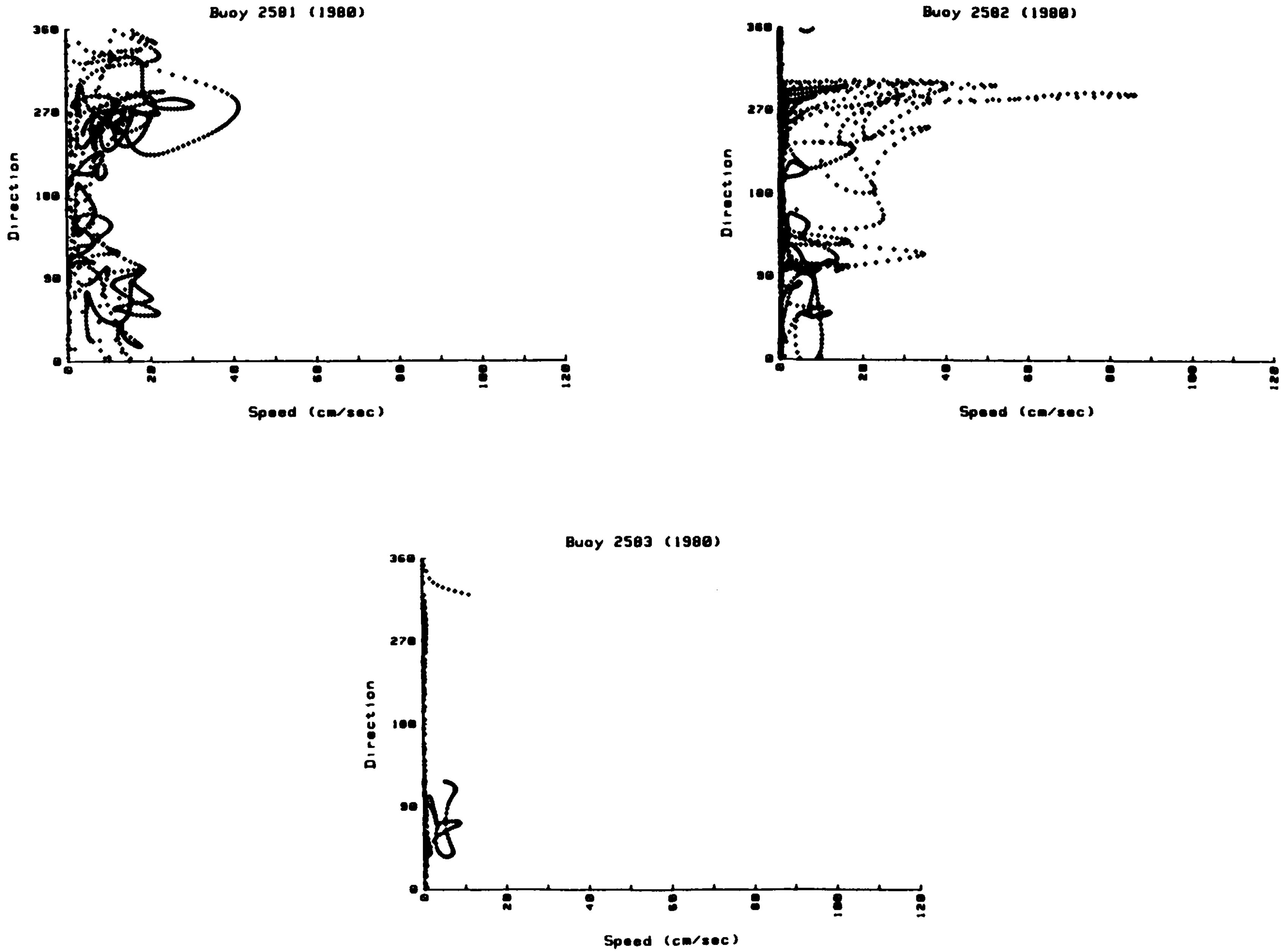
FIGURES A-12d through A-12f. HISTOGRAMS OF DIRECTION - BUOYS 4538, 4538a, AND 4539 (1985)

APPENDIX B

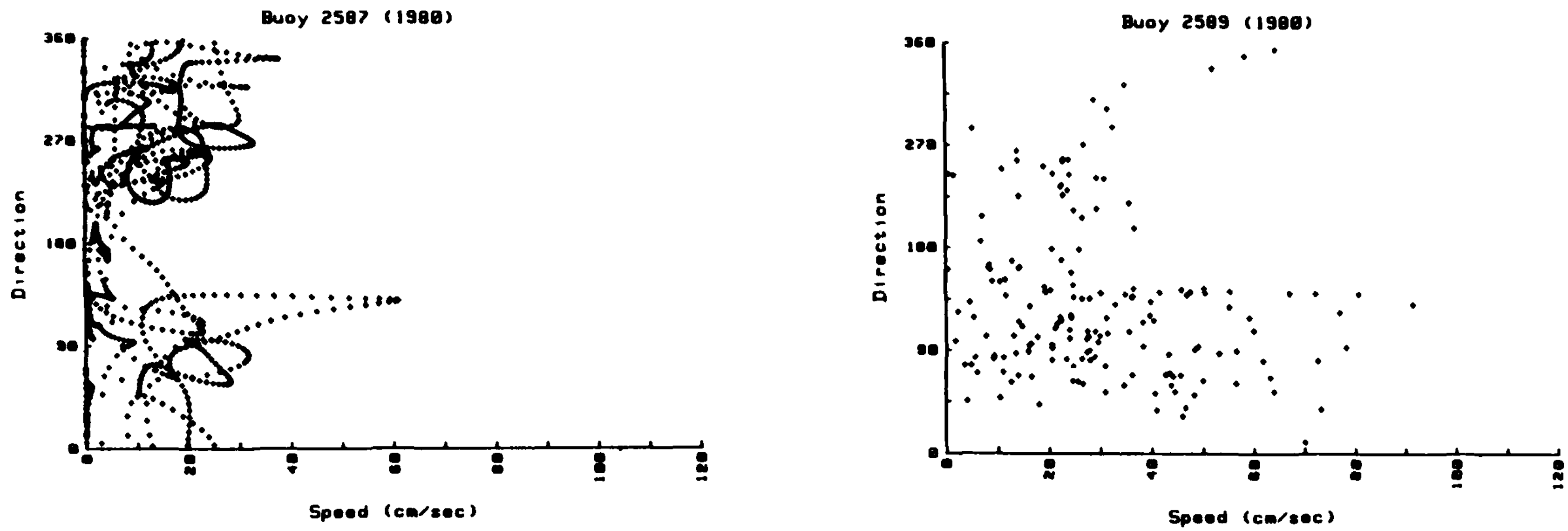
Scatterplots of Direction versus Speed for Selected Buoys



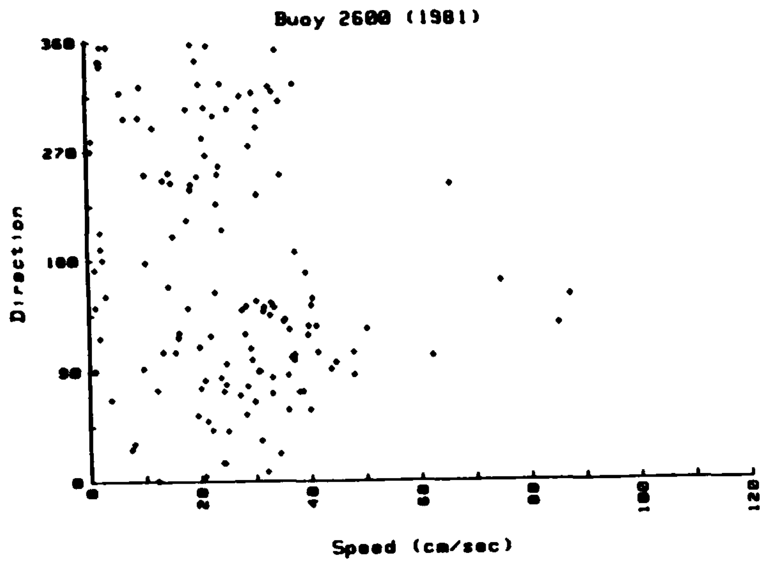
FIGURES B-1a through B-1c. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 226, 432, AND 443 (1979)

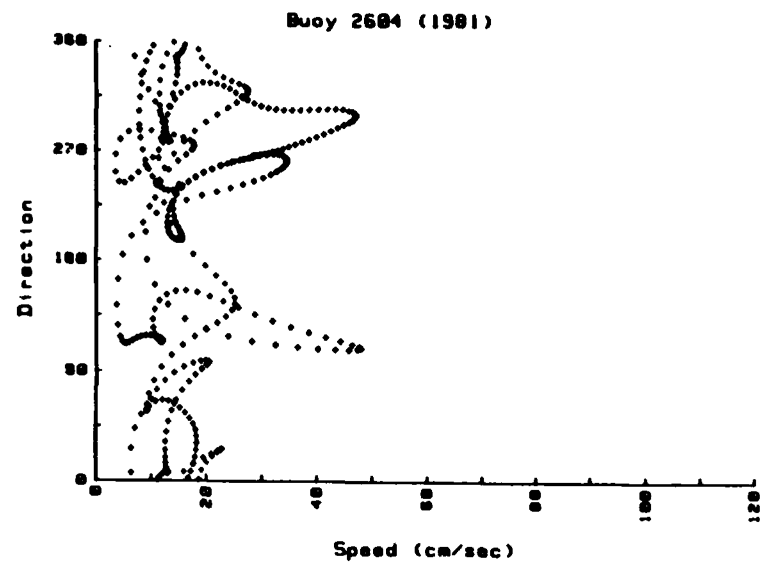


FIGURES B-2a through B-2c. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 2581, 2582, AND 2583 (1980)

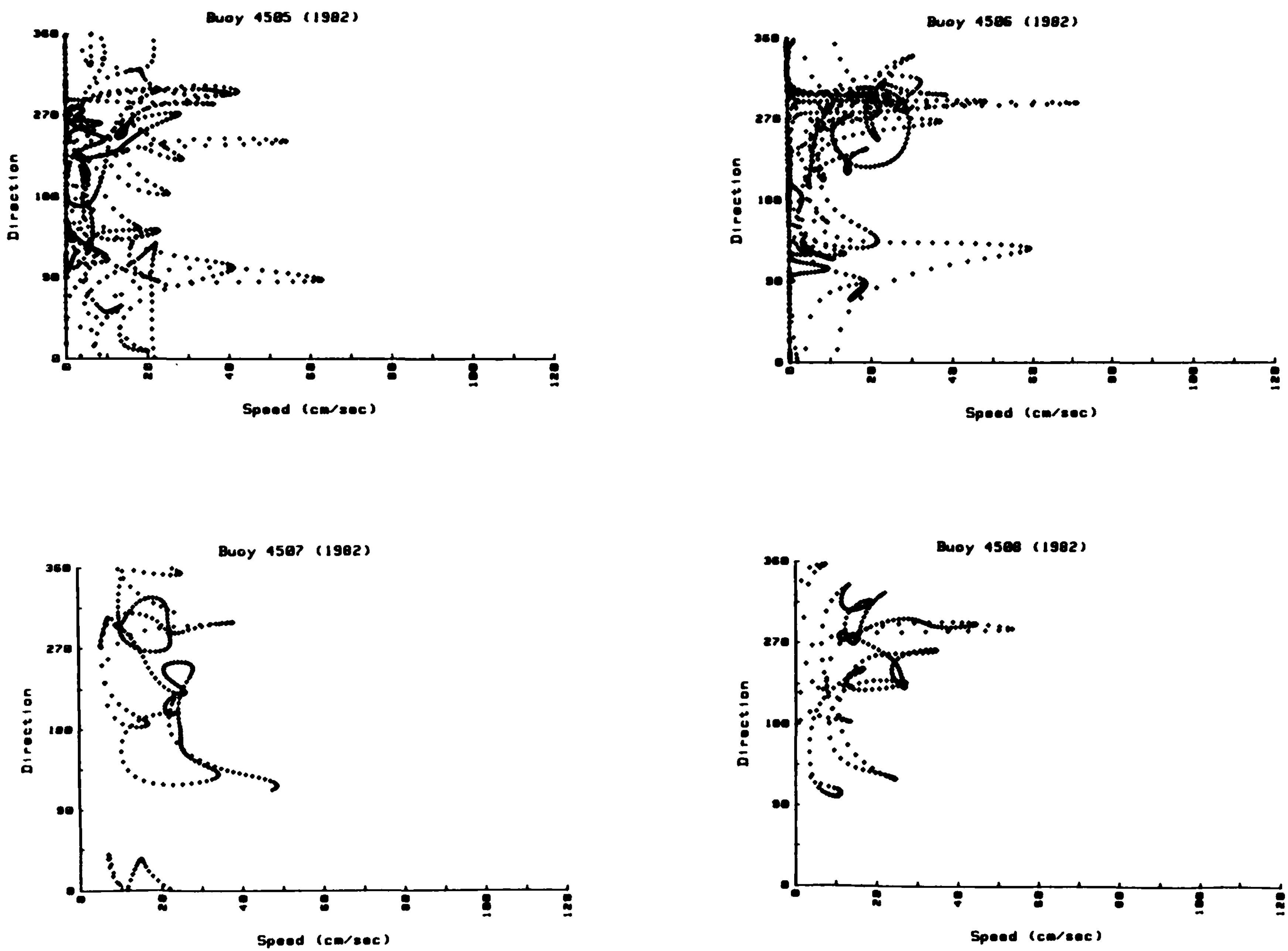


FIGURES B-2d and B-2e. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 2587 AND 2589 (1980)

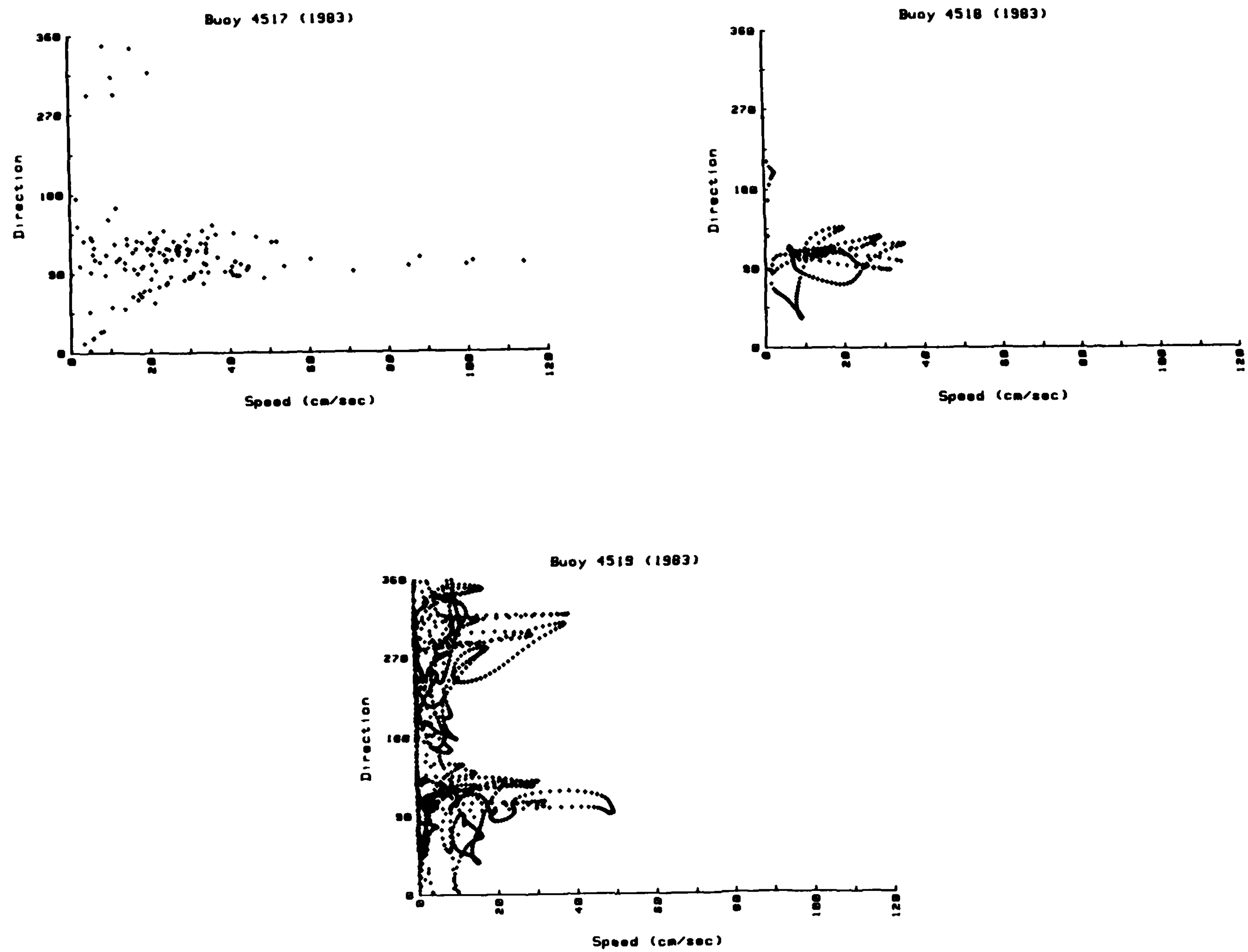




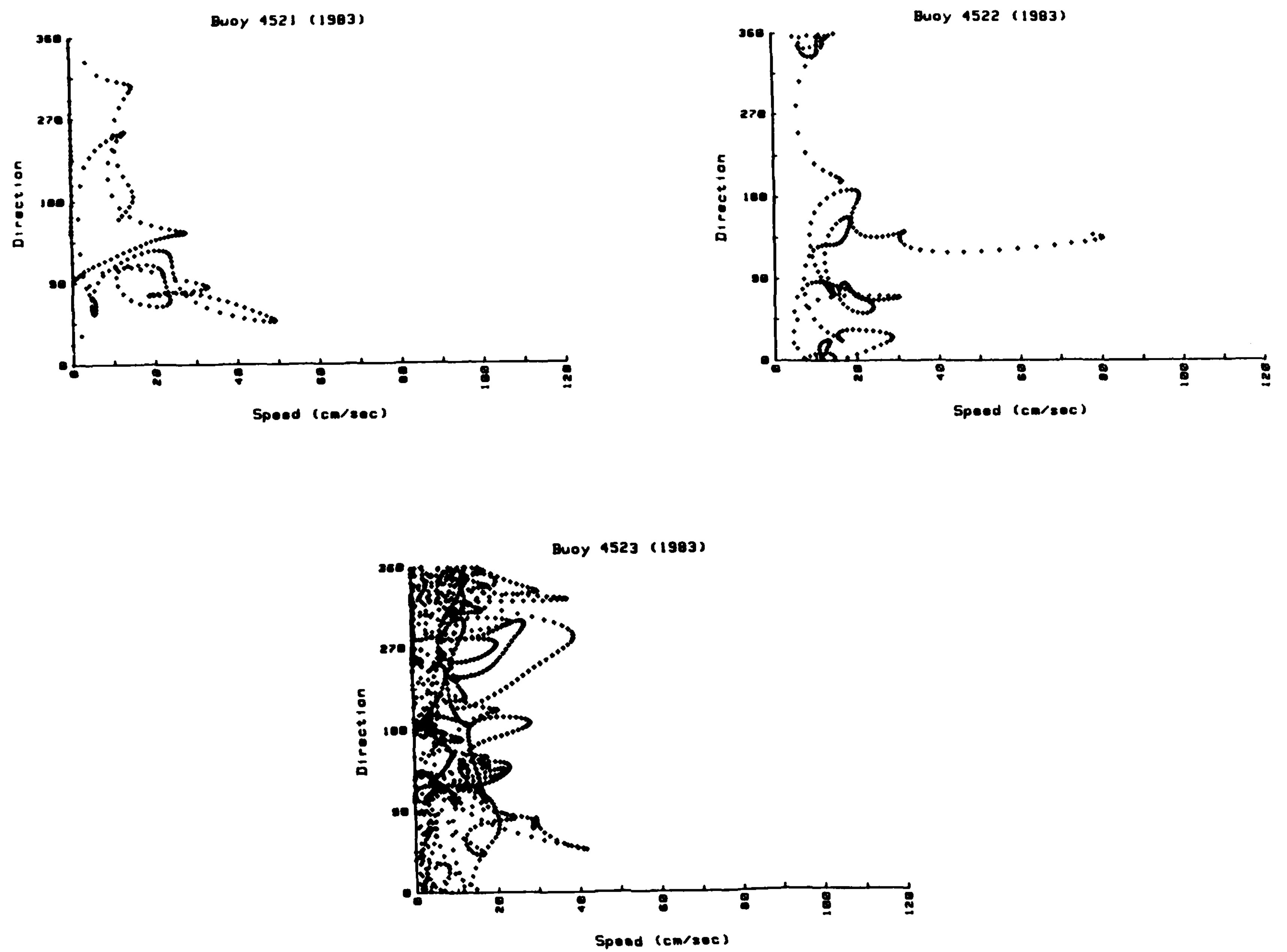
FIGURES B-3a and B-3b. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 2600 AND 2604 (1981)



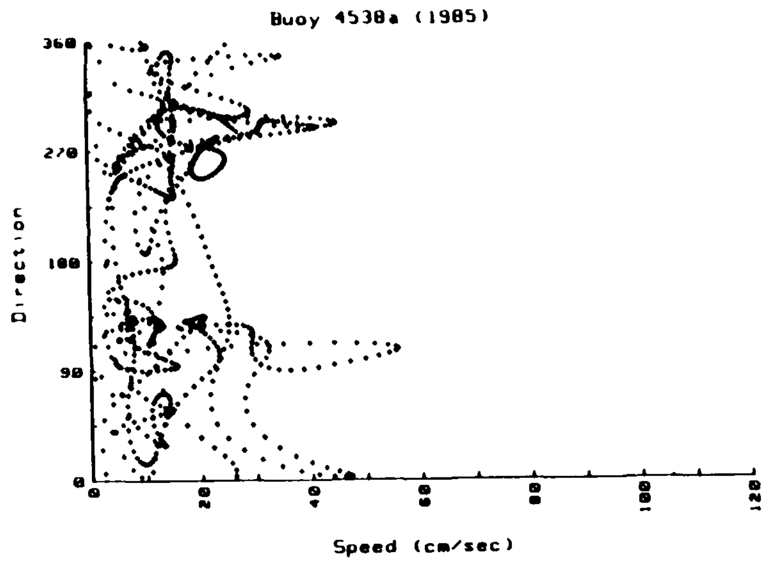
FIGURES B-4a through B-4d. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 4505, 4506, 4507, AND 4508 (1982)

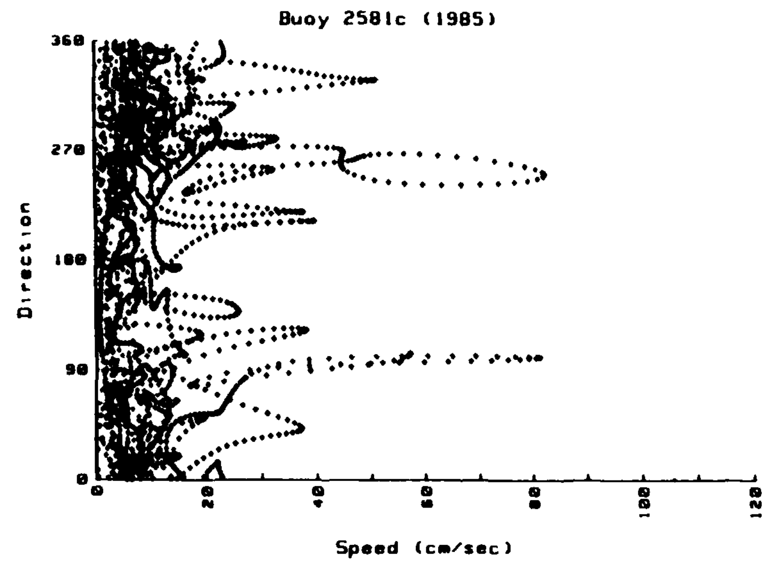


FIGURES B-5a through B-5c. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 4517, 4518, AND 4519 (1983)



FIGURES B-5d through B-5f. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 4521, 4522, AND 4533 (1983)





FIGURES B-6a and B-6b. SCATTERPLOTS OF SPEED VS DIRECTION - BUOYS 4538a AND 2581c (1985)

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